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Faiers, Gregory Edward

THE FORMATION AND GEOGRAPHIC RELOCATION OF JANUARY DIURNAL PRECIPITATION PATTERNS IN LOUISIANA AND SOUTHEASTERN TEXAS

The Louisiana State University and Agricultural and Mechanical Col. PH.D. 1986

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THE FORMATION AND GEOGRAPHIC RELOCATION OF JANUARY DIURNAL PRECIPITATION PATTERNS IN LOUISIANA AND SOUTHEASTERN TEXAS

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

Geography

by
Gregory E. Faiers
B.A., Memphis State University, 1978
M.S., Memphis State University, 1980
May, 1986

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ABSTRACT

The diurnal patterns of hourly precipitation events in Louisiana and southeastern Texas in January have varied over space and time. Distinct spatial patterns were observed so that southern Texas had morning maximums throughout the study period while a southwest to northeast band of morning precipitation shifted south and east from eastern Texas in the 1950's into central Louisiana in the 1960's and 1970's. Southeastern Louisiana maintained an afternoon pattern throughout the period.

The morning precipitation in southern Texas is the result of the diurnal variation in cyclogenesis, especially off the Texas-Gulf coast. A southwest to northeast band of mid-morning precipitation peaks is the result of the northeastward migration of weak disturbances which move to the northeast with the southwesterly flow aloft, well in advance of the Texas-West Gulf cyclone.

The band of mid-morning precipitation and its' associated transition zone to afternoon peaks shifted to the south and east in the 1960's and 1970's due to the more southerly displacement of the polar front. There is much evidence to support this more southerly postion of the polar front, including colder temperatures across the study region, a much greater frequency of frontal overrunning rainfall events at Lake Charles in the 1960's and 1970's,

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and stronger winds and lower pressures aloft at Brownsville since 1958.

The transition zone between morning and afternoon precipitation maximums shift to the Florida panhandle in February according to other researchers This shift takes place because the mean position of the arctic high shifts eastward as does the axis of the arctic air outbreaks across the eastern United States. Storm tracks in the south and eastern parts of the United States are also displaced eastward in late winter and spring.

This research is of interest to weather forecasters, not just in Texas and Louisiana, but also throughout much of the southern and eastern United States. Previous research of diurnal precipitation patterns has not focused on changes in diurnal patterns over time. This study indicates that diurnal patterns can shift markedly with climatic fluctuations.

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CHAPTER I

INTRODUCTION

Diurnal Rainfall Variability

Climatologists have long been intrigued by diurnal rainfall patterns and the processes involved in creating them. The afternoon maximums found throughout much of the eastern United States in the summer are readily explained by the afternoon convective activity. But in some cases, diurnal patterns are extremely variable and conclusive statements about such patterns are nearly impossible. In other cases, however, diurnal patterns are quite pronounced in the morning or overnight; they present challenging problems for analysis of the processes involved in the creation of these patterns. This becomes even more intriguing when diurnal patterns vary distinctly over relatively short distances, especially when the trends are consistantly evident over space and time. A situation such as this, where diurnal precipitation patterns have changed over space and time, exists in Louisiana and southeastern Texas in January.

Preliminary research of diurnal rainfall patterns in January during the standard climatic period of 1951 through 1980 at Lake Charles, Baton Rouge and New Orleans revealed that a distinct morning peak in rainfall centered around 9

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a.m existed at Lake Charles. In contrast, a more variable but discernable afternoon peak was observed at both Baton Rouge and New Orleans. When the time-series was organized into three 10-year periods, it was found that the diurnal patterns of New Orleans and Lake Charles were significantly correlated in the 1950's (.732 Pearson product moment correlation), but that the morning maximum which emerged at Lake Charles in the 1960's and 1970's caused this relationship to break down (-.141 in the 1960's and -.361 in the 1970's). The month of January was chosen for analysis because in this region it is the only winter month which tends to escape influence from patterns typical of the preceeding and following seasons.

Further analysis revealed that an abrupt transition zone existed during the 1960's and 1970's along the Louisiana coast between Lake Charles and Morgan City. This transition zone was located in the Texas coastal zone between Victoria and Galveston during the 1950's. The purpose of this research is to further study the causes for the abrupt morning-afternoon boundary in Texas and Louisiana and why this boundary shifted during this period. The geographical extent of the research has been broadened to include all of Louisiana and the southeastern third of Texas.

A review of the literature relevant to this research is conducted in Chapter Two. A wide variety of sources have been consulted, primarily in order to review diurnal precipitation studies, to survey methods of data analysis,

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and to examine aspects of regional and global climate which relate to the changes in the diurnal precipitation patterns.

The general framework of this research revolves around the variation of hourly precipitation events over space and time. This has been achieved by constructing the diurnal patterns for over 40 stations in Louisiana and Texas from data gathered by N.O.A.A. (Hourly Precipitation Data). The organization of these data, the problems inherent to the data and the method used to define peak hours are discussed in Chapter Three.

The geographical patterns associated with the individual diurnal distributions have been arranged by analyzing those locations and their relationships with various diurnal patterns throughout the study area. This has been accomplished through the mapping of correlation fields. A geographic pattern emerges which indicates a distinct transition zone between the morning and afternoon peaks. The location of the transition zone in the 1950's and 1960's has been determined and is discussed in Chapter Four.

A qualitative model, based upon known meteorological processes which are actively present in the study region has been developed and is discussed in detail in Chapter Five. Factors such as diurnal variability of cyclogenesis, shifting in mean location of the polar and subtropical jet streams, and the determination and significance of storm tracks are involved in this

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qualitative model.

To analyze the surface weather conditions which create a morning and afternoon maximum, all hours of measureable precipitation at Lake Charles were classified by synoptic weather type (Muller, 1977). Since Lake Charles is one of the stations to undergo a shift in diurnal patterns and hourly weather conditions were available from that station, it was chosen for this analysis and a discussion of the results appears in Chapter Six. The results of this analysis will reveal which synoptic weather type was most responsible for the peak, as well as help in understanding other factors involved in diurnal rainfall variability.

Since much of this research is concerned with the processes involved in the formation of a diurnal precipitation transition zone, the findings are of interest to meteorologists, especially forecasters. The location of the transition zone as well as the timing of the shift of the transition zone is of interest to climatologists. This research will broaden our knowledge of the processes involved in the formation of diurnal precipitation patterns and their shifts as well as reveal the diurnal variability of cyclogenesis in the western Gulf of Mexico. The relationship between diurnal precipitation patterns and upper air conditions, including the positioning of the polar front and its' shifting over time will be better understood.

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The Physical Setting

The climate of Louisiana and southeastern Texas (see Figure 1-1) in January can be best described as cool and damp. Occasionally, very cold Arctic outbreaks may send temperatures into the teens in southern sections of this region and to near zero in the north. Temperatures average from near 60 degrees at Brownsville to 47 degrees at Shreveport.

Average rainfall totals for the month of January vary from less than an inch at Eagle Pass and Laredo, Texas to over four and one half inches a month at New Orleans. Excessive amounts of rain are relatively rare at this time of year but extended periods of light to moderate rain have produced sizeable monthly totals such as 10.78" at Corpus Christi in 1958, 12.62" at New Orleans in 1966, and 12.69" at Lake Charles in 1974. In the southern half of the study area, snowfall is rare. In northern Louisiana and northeastern Texas, snowfall events vary in frequency from year to year but are observed in most Januaries.

The terrain of the region is fairly uniform from the Brownsville area through Houston to Baton Rouge and New Orleans. This is the Gulf Coastal Plain and it is characterized by low relief (Hunt, 1966). The extreme western part of the study area, near Laredo, Eagle Pass and San Antonio is higher in elevation (over 500 feet) and is still considered to be in the coastal plain. The landscape of northern Louisiana and northeastern Texas is

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characterized by rolling hills interspersed with broad alluvial valleys. On a regional scale, relief plays little role in rainfall and temperature patterns and the dominant climatic controls are latitude and distance from the Gulf of Mexico.

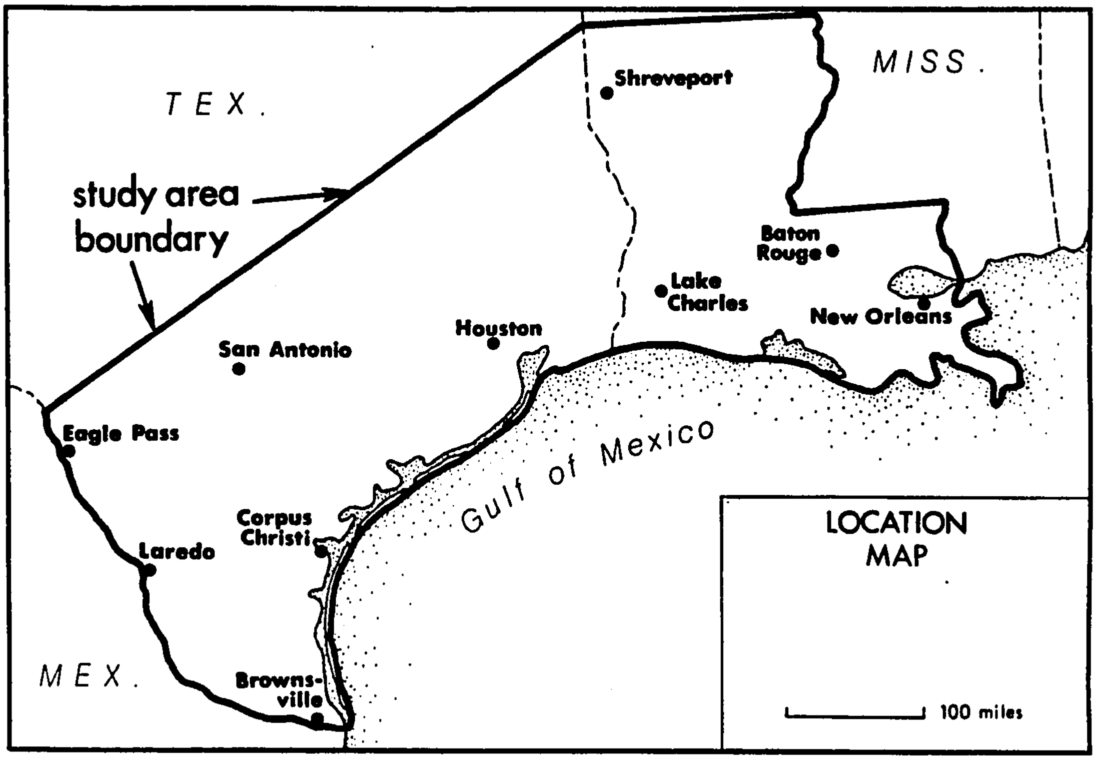

Figure 1-1 Generalized map of the study area.

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CHAPTER II

LITERATURE REVIEW

The purpose of this chapter is to review the literature relevant to this research. The relevant literature is divided into three catagories:

a)diurnal precipitation variability
b)cyclogenesis and storm tracks in the Gulf of Mexico
c)methodology

Because this research is grounded in diurnal rainfall variability, a survey of the development of research in diurnal precipitation is essential. Studies of cyclogenesis in the western Gulf of Mexico are important since much of the rain that falls in January over southeastern Texas and much of Louisiana results from Texas-West Gulf cyclones. A review of data manipulation and synoptic weather approaches is vital to the conclusions found in Chapters Four and Six.

Diurnal Precipitation Variablity

The study of diurnal precipitation variability has been approached in a variety of ways over the course of this century. Early studies centered on local patterns during 5 to 30 year periods. Examination of 30-year patterns was not possible until the late 1920's since instruments capable of yielding accurate hourly totals were not widely in use until the late 1800's.

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A study of New Orleans diurnal precipitation patterns for the 1897-1928 period was undertaken (McDonald, 1929) and revealed diurnal patterns in January similar to those found in this research. McDonald also examined hourly precipitation probabilities for each month using this 30-year data set. A similar study of diurnal precipitation at Mobile, Alabama (Armstrong, 1934) was more descriptive and less analytical than was McDonald's study.

The processes involved in creating diurnal variations of rainfall were of interest to two British scholars in the late 1930's and 1940's. E.W. Hewson (1937), in a comprehensive study of "rainfall in depressions" examined, among other things, diurnal rainfall patterns associated with warm fronts. Hewson concluded that there was a nocturnal peak in warm frontal precipitation. He explained that radiational cooling would affect the instability of the atmosphere nocturnally, therefore increasing precipitation in the warm frontal zone at that time.

R.V. Dexter (1944) expanded upon this topic in a more detailed analysis of warm frontal precipitation. Dexter, through a series of diagrams, depicted the diurnal changes in areas receiving rainfall in the zone north of the warm front. He concluded that the rain shield north of the front covers a greater area during the night and decreases during the day. The increase in coverage during the nocturnal period is due, according to Dexter, to greater potential instability at night and secondarily to

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radiational cooling of the cloud tops (Dexter, p. 132).

Interest in diurnal rainfall variability seemed to decline in the 1950's and 1960's. During this time, much of the information on diurnal precipitation patterns was confined to brief descriptions buried within local or regional climatological examinations. In Robert Orton's The Climate of Texas (1964), for example, the hourly frequencies of rainfall at several stations in Texas are displayed, but not discussed. In a study entitled The Climate of Central and Coastal Texas Watersheds (1961), a summary of diurnal rainfall variability over a five-year period at seven stations was included. Despite the short study period, some trends were revealed.

As the computer became increasingly utilized as a research tool in the 1970's and 1980's, studies of diurnal rainfall patterns began to reappear. The thousands of entries required to study hourly rainfall over a 30-year period at just one station undoubtedly limited the scope of many diurnal precipitation studies prior to the application of computer technology. However, beginning with Wallace's study (1975) of diurnal variations in precipitation and thunderstorm frequencies in the United States, a new direction in diurnal precipitation studies unfolded. Not only was the scope of Wallace's study unprecedented, but the findings, which incorporated atmospheric theories never before related to diurnal precipitation patterns, stimulated further study. Wallace found that thunderstorms increase in intensity nocturnally and related

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this diurnal pattern to the increase in the velocity of winds at upper levels during the night, which in turn enhances the thunderstorm activity. Crysler, et al. (1982) also found a nocturnal peak in rainfall intensity, concluding that the night and early morning hours were the most likely time for excessive events which would lead to flash flooding in the eastern and central United States.

The use of the computer has also stimulated more descriptive studies. In a regional study of Kentucky, Conner (1981) examined diurnal patterns in four regions of the state on a seasonal basis. Conner studied the diurnal frequencies of measureable events, maximum events and average intensities. His findings were not unexpected and the diurnal patterns of excessive events were in line with Wallace's conclusions.

In a more detailed and sophisticated study, Chen et al. (1983) examined the winter diurnal precipitation patterns of the coastal area of northern Taiwan and how they were related to diurnal circulation. They found a morning maximum centered on 5 a.m. and considered this peak to be the result of "the decrease of static stability caused by the nightime infrared radiational cooling effect at the cloud top in addition to local convergence" (p. 2274). Local convergence is due to the land-sea interaction and leads to offshore flow nocturnally which then interacts with the prevailing large-scale northeasterly flow (p. 2273). Such convergence undoubtedly occurs along the Texas coastal zone, especially when a

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stationary front is poised offshore.

Of even more relevance to this research is a study of diurnal precipitation patterns in Florida by B.E. Schwartz and L.F. Bosart (1979). During the winter months, Schwartz and Bosart found an "abrupt change" in the diurnal precipitation patterns across northwest Florida between Lamont and Dowling Park (Figure 2-1), a distance of 35 miles (p. 1538). According to Schwartz and Bosart, "most of the north-central area exhibits a late morning maximum, but further south a gradual transition to early and mid-afternoon occurs" (pp. 1538-39). "West of Lamont, Schwartz and Bosart continue, "all stations show a consistent tendency for an early morning maximum... The location of this transition zone coincides remarkably well with the axis of the winter quasi-stationary front" (p. 1544). Schwartz and Bosart conclude that this pattern is most pronounced in late winter. The relationship between this transition zone and the transition zone of the western Gulf states region forms the basis for the review of literature relevant to "West-Gulf lows."

The greatest weakness of all of these studies is that they have all considered diurnal precipitation patterns to be constant over time. By lumping 30 years or more of data into one set for analysis, trends over time are never revealed. Therefore, it is not known, for example, if the transition zone discovered by Schwartz and Bosart in the Florida panhandle has remained in that position historically.

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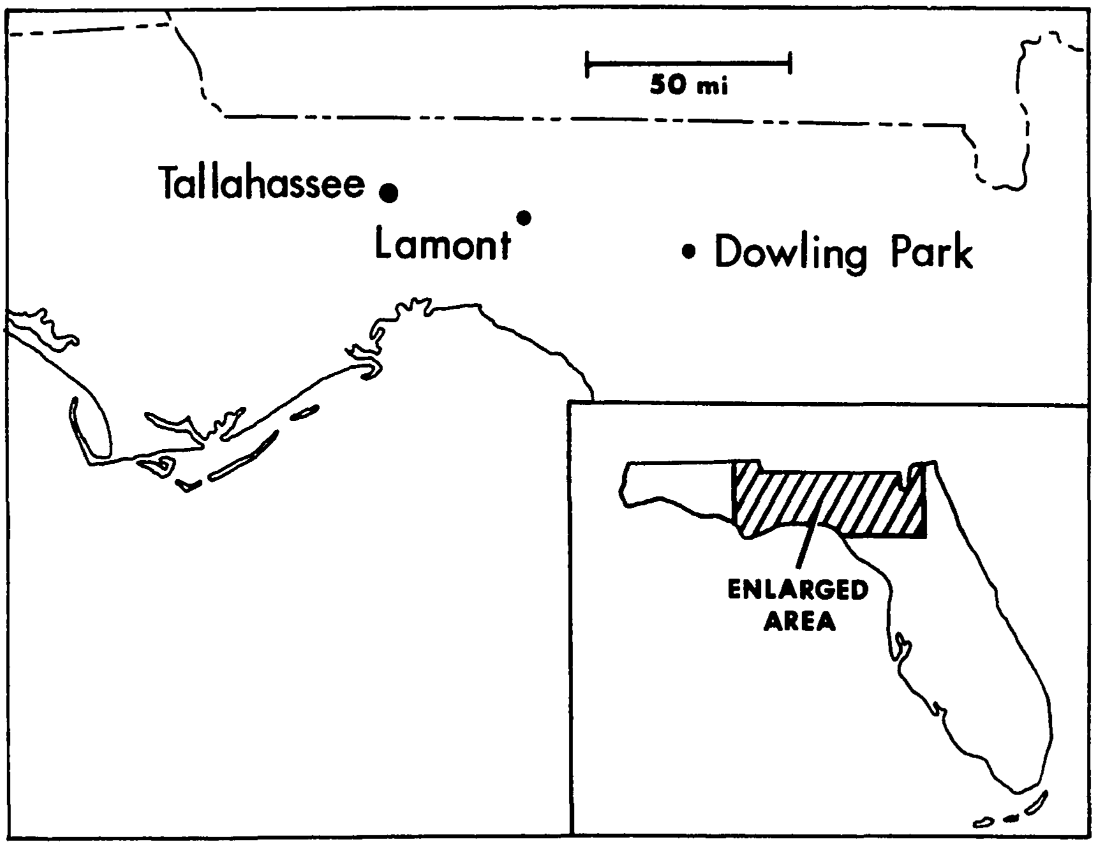

Figure 2-1 Location of the transition zone between morning and afternoon precipitation peaks as found by Schwartz and Bosart (1979).

West Gulf Cyclones

Over the years, several studies of cyclogenesis and storm tracks related to West Gulf cyclones have been conducted. The most detailed analysis was that of W.J. Saucier in his article "Texas-West Gulf Cyclones" (1949). Saucier found that in order for cyclogenesis to occur in the western Gulf, there must be "polar or arctic air at the surface over the United States." Suacier continued, "It is evident that the polar front, an accepted mechanism in the general circulation, does partake in this coastal

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cyclogenesis" (p. 220). He also found that, over the period 1900-1940, the distribution of cyclone frequencies "is represented by an almost symmetrical curve centered on January" (p. 225). Saucier concluded that the "great frequency with which surface cyclones eminate from the Texas-West Gulf coastal region can be accounted for by the unique physiography of the environment. In addition to control by the general circulation, frontogenesis and cyclogenesis in this region are favored by influences of the warm-water surface of the Gulf of Mexico providing both a temperature contrast and moisture source... The frequency with which the polar front is in the vicinity of the north Gulf coast and the natural land-water contrast in winter make the coast a semi-permanent low-level frontal zone..." (p. 231).

G.A.Johnson, et al. (1985) also emphasized the land-sea temperature gradient as a causal factor in cyclogenesis. They found that the physiography of the region played a role as well in cyclogenesis. According to Johnson, et al., "... the combination of the shape of the coast and the sea surface isotherms can have an important effect in establishing a meso-scale atmospheric circulation. The sea-level isobars tend to parallel the shape of the coast, with pressure decreasing with distance from shore as the boundary layer is progressively warmed by the sea surface" (p. 3). Such a reformation of pressure patterns and wind fields was also found along coastal Taiwan during the winter by Chen, et al. (1983) and the

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general processes of this development was examined by C.B. Pyke (1965).

The typical Texas-West Gulf cyclone is relatively unorganized and weak. However, there have been some cases of severe storms developing during the winter and some of these have been studied. Some of the strongest Texas-West Gulf cyclones of recent history developed in the winter of 1982-83 and were the focus of the paper by Johnson, et al. (1985). Other storms in 1954 led to an examination by L.P. Stark and D.A. Richter (1954). These studies were primarily interested in forecasting problems, however.

Several studies of storm tracks in the United States have been undertaken. Since many of the Texas-West Gulf cyclones are weak and not well defined until they have moved well east or northeast, many of these studies have failed to cover Gulf storms in detail. For example, C. H. Reitan in a heavily cited study, never recognized the western Gulf as a region of cyclogenesis even though Saucier (1949) and R. D. Elliott (1949) both recognized that many of the fabled "northeasters" of New England originated as Texas-West Gulf cyclones.

An early examination of North American storm tracks by E.H. Bowie and H. Weightman (1914) did include extensive documentation of Texas-West Gulf cyclones. This study did indicate that December was the peak month of cyclonic activity in the western Gulf and January was second in frequency. Saucier alluded to this minor discrepancy with his findings, which concluded that January was the peak

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month, but he could not explain it. Saucier did note that for the period from 1899 to 1912 a December maximum existed but that during the remainder of his study period, January maximums were most common (Saucier, p. 225). Bowie and Weightman found that there was an eastward shift in frequencies and tracks in February, the peak time for the Florida diurnal precipitation transition zone. The land-sea temperature contrast, the presence of the polar front and the reformation of the front into a more "wave-conducive shape" are the key factors in Texas-West Gulf cyclogenesis. G.W. Bomar (1983), however, added another dimension when he concluded that "these surface storm centers are given birth as a result of the configuration of the belt of very strong winds racing northeastward across the Gulf at high altitudes" (p. 37). The storms move in an east or northeasterly direction out of the western Gulf.

Cyclones tracking out of the western Gulf have been observed to follow two well-defined paths (Elliott, 1949). One of the two paths tracks lies between Lake Charles and New Orleans while the other is over the Florida panhandle (Figure 2-2). These two tracks correspond remarkably well with the two diurnal precipitation transition zones which have been observed along the Gulf coast in the winter months.

Methodology

There are primarily two aspects of the methodology employed in this research which required an extensive

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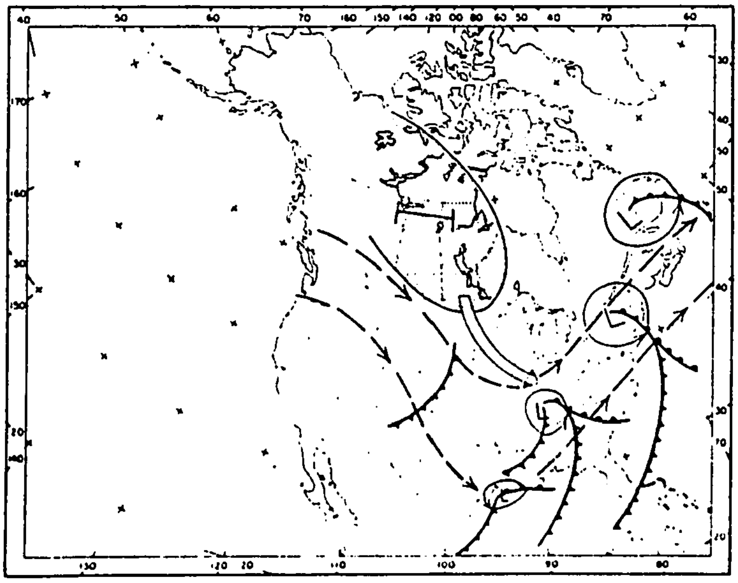

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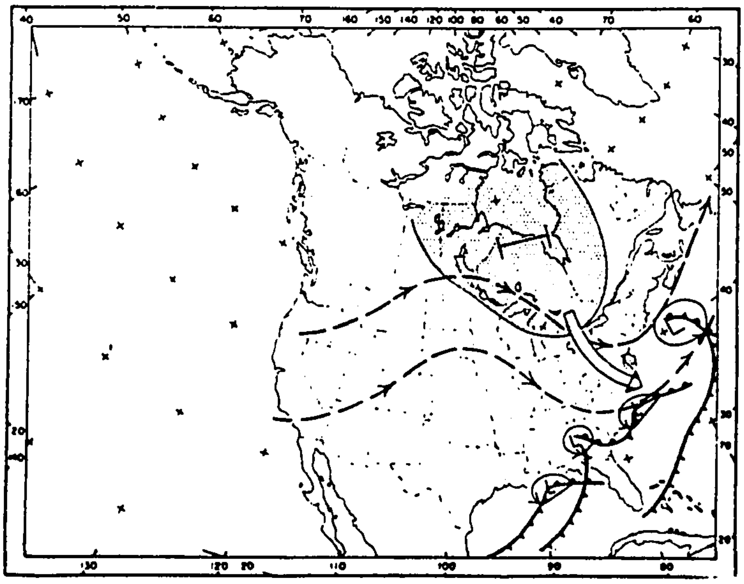

Figure 2-2 The two tracks taken by Texas-West Gulf cyclones (types Ga and Gb) from Elliott (1949).

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review of the literature. These two aspects are 1) the mapping procedure utilized in Chapter 4, and (2), the synoptic weather type classification system used for isolating the climatic factors involved in the Lake Charles diurnal precipitation variability.

Correlation Field Analysis

The mapping of diurnal patterns in Chapter 4 is primarily accomplished by means of correlation fields. This technique is used to determine the spatial extent of the area which is significantly related to the diurnal pattern at any location in the study area.

Correlation fields have been used to help explain the relationships between daily, monthly and and annual rainfall patterns with upper air conditions (Stidd, 1954, and Lund, 1971). Correlation fields have also been utilized to determine the spatial linkages between rainfall at one location and other locations within a given study area. Huff and Shipp (1968, 1969) found that correlation decay from a given station in the Midwest is greatest for air-mass showers and least for cyclonic situations.

Graham Sumner (1983) used this method to determine the general trends in the spatial patterns of daily rainfall on a monthly basis in eastern New South Wales. Sumner determined the spatial patterns of correlated locations in association with two stations for all twelve months. These patterns shifted seasonally, especially between summer and winter patterns.

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The few diurnal precipitation studies which did attempt to map patterns did so by determining the harmonic means (Schwartz and Bosart, 1979) and determining the amplitude and phase of the diurnal cycles. The data were displayed on a map either in the form of arrows oriented to indicate the diurnal maximum or by simply labeling the time of maximum frequency at a given location. The correlation field approach was not used in these studies, but it is used here to allow for better visualization of the patterns.

Synoptic Weather Type Analysis

Arnold Court (1957) referred to synoptic weather type analysis as "map pattern climatology" (p. 131). According to Court, "Map pattern climatology relates surface weather conditions within an area to the general pressure and flow patterns over a much larger region" (p. 132). Synoptic weather types have been determined for several places around the world and have been applied to many aspects of climatic impacts.

For North America, R.D. Elliott determined 20 to 30 types over 45 degrees of longitude (Court, p. 132). Another approach, the "map window," was the basis for a U.S. Air Force study which concluded that there were 14 distinct "map types" in the Texas window, including approximately the western one half of the study area in this research.

Even though there are data available for the map

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window approach, this method was not chosen for this analysis because of it's inability to focus on patterns relevant to this research. For example, the only map type in which a low pressure center is situated off the Texas coast is supposedly most frequent in September, with only three such observations in January over the 1946 - 1971 period (p. 4-13). This map window approach does not differentiate between storms of tropical or subtropical origin and is, therefore, inappropriate for incorporation into this research.

Robert Muller (1977) has classified Louisiana synoptic weather conditions into 8 types. Variability of several atmospheric properties has been determined (Muller and Willis, 1982) and climatic impacts on water level fluctuations (Wax, 1977) and air pollution (Muller and Jackson, 1985) have been found to vary significantly by these weather types. In Chapter 6, this classification is used to determine the synoptic weather types associated with hourly precipitation patterns at Lake Charles.

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CHAPTER III

DIURNAL PRECIPITATION PATTERNS IN LOUISIANA AND SOUTHEASTERN TEXAS

The purpose of this chapter is to discuss the methods used in the construction of diurnal precipitation records for the stations included in this research. The data are analyzed by decade, and a method has been devised which indicates peak hours in the distribution of hourly precipitation events.

The data utilized in this research were derived from the Texas and Louisiana volumes of the N.O.A.A. publication Hourly Precipitation Data, except for January of 1951 when the hourly precipitation data were included in the Texas and Louisiana volumes of Climatological Data. In the original format, the amount of precipitation which fell in any hour was included. For instance, between the hours of 5:00 and 6:00 a.m. on January 2, 1977, at Corpus Christi, Texas, 0.02" of precipitation was recorded. The data entry then reads: 6:00 a.m: .02.

Throughout the 1950's, all stations recorded hourly rainfall with gauges which measured precipitation to .01". At many "second order" stations, most of which were stations in rural or small town settings, new Fisher-Porter gauges were installed in the late 1960's and these gauges

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recorded rainfall by 0.10" increments. Hence, the data are not compatable over the study period because of the change in recording gauges. Furthermore, at Galveston, for example, over the 30 year period from 1951-80, 79.5% of all hourly events were less than .10". This means that with the Fisher-Porter gauge, the exact timing of events less than .10" cannot be determined because the gauge does not "read" these events until enough of them accumulate to equal 0.10". This is the case even though events of magnitudes under 0.10" represent the majority of hourly events in January.

Because of these problems, some of the stations included in the 1950's were dropped in the 1960's. Those stations where the Fisher-Porter gauges were introduced in the 1960's were included only when no more than two Januaries were measured with the Fisher-Porter gauges. The month or two that were measured by the new gauge had to retain patterns significantly related to the patterns which emerged from the first eight or nine years of "older" gauge data. The significance of the relationship was determined by Pearson Product Moment correlation. Stations included in this study which underwent such a change are noted.

By the end of the 1970's, only four stations in Louisiana retained the "universal" gauges which measure hourly precipitation less than 0.10". There were too few universal gauges in Louisiana during the 1970's to allow for a continuation of the detailed analysis of hourly precipitation patterns. However, the data from the four

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universal gauges in operation in Louisiana during the 1970's reveals that the patterns which emerged in the 1960's changed little in the 1970's.

In some cases, one or two Januaries were missing from the data set. Again, these stations are duly noted and they are only included in this study if they retain patterns which appear consistent with the other years included in the study as well as if they do not appear as an anomaly with neighboring stations.

The entire study area, with the locations of the stations listed above, is mapped in Figure 3-1. The stations within the study area, the decades in which the stations were active (using universal gauges) and the abbreviations for each station appear in Appendix A.

As comprehensive a network as possible has been attained given the deficiencies of the data. The worst spatial coverage in the study area is in Southeast Louisiana where no stations are included east of French Settlement and north of New Orleans. Some stations have been active in that region, but none for a long enough time to merit inclusion in this study.

Manipulation of the data

The data for each station have been arranged by decade in terms of the raw frequency of measureable events per hour. Along with this, a three-hour moving average of events has been calculated in order to "smooth" the data. This was done in order to isolate and visualize trends in

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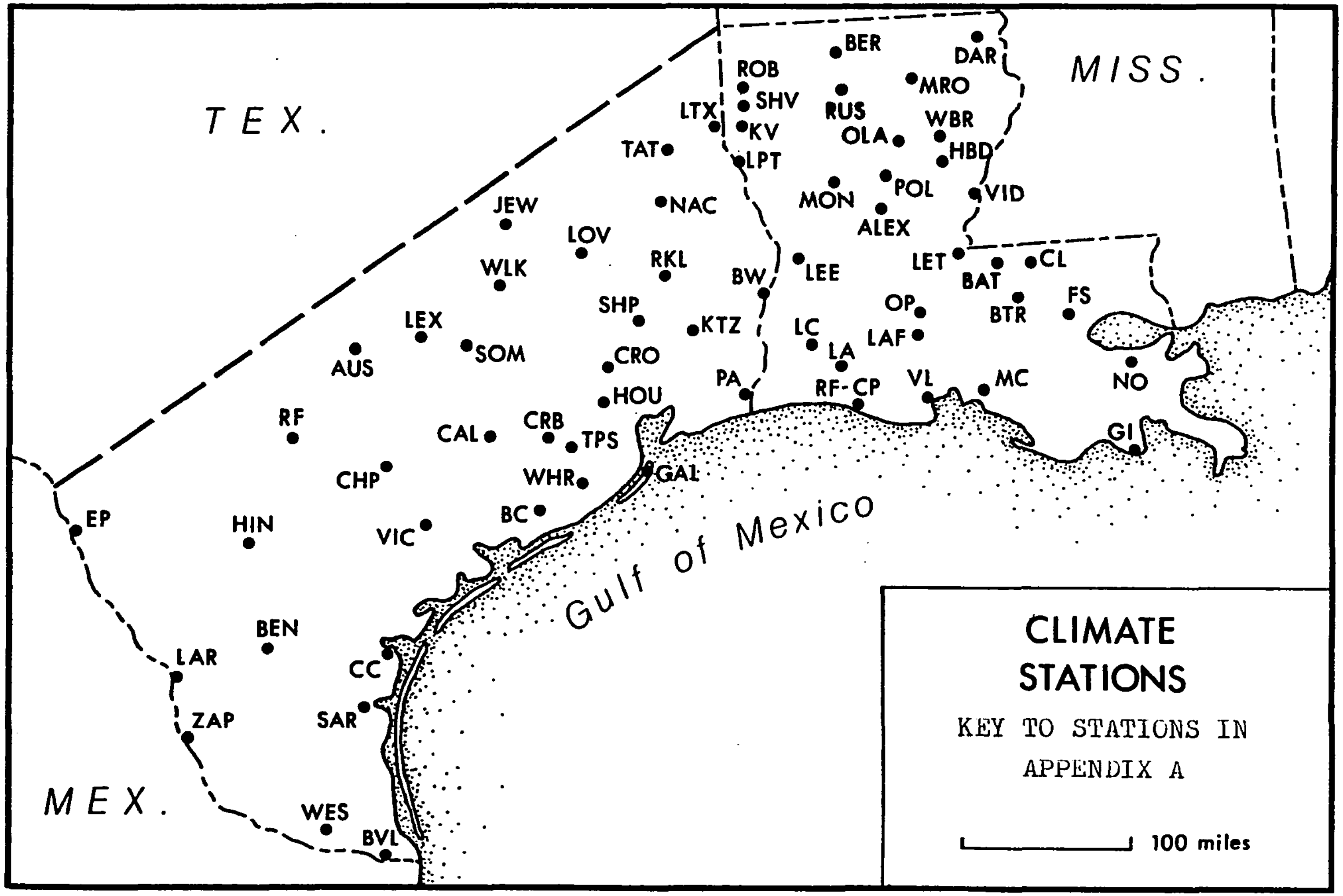

Figure 3-1 Locations of climatic stations included in this study.

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the data. The frequency of events at each hour at some selected stations and their smoothed distribution are shown in Table 3-1 and Figures 3-2, 3-3 and 3-4.

Table 3-1. Frequency of measureable hourly precipitation events during January in the 1950's at Brownsville, Galveston and Lake Charles.

	BROWNSVILLE		GALVESTON		LAKE CHARLES	
time	freq.	3-hour	freq.	3-hour	freq.	3-hour
0100	12	11	9	9	10	13
0200	13	13	8	9	12	11
0300	15	15	9	8	12	11
0400	18	15	7	10	9	10
0500	12	15	13	10	9	10
0600	15	12	9	12	11	11
0700	9	11	15	14	14	13
0800	8	8	17	14	15	16
0900	7	8	11	15	20	17
1000	10	9	18	14	16	17
1100	11	11	12	14	15	16
1200	11	9	13	13	18	16
1300	4	8	14	14	14	16
1400	8	7	16	16	17	18
1500	8	7	17	18	22	20
1600	6	6	19	17	22	21
1700	3	5	16	17	18	20
1800	5	6	15	14	21	18
1900	10	8	12	14	14	17
2000	8	10	14	14	16	16
2100	11	9	16	14	17	16
2200	9	10	12	13	15	16
2300	9	9	12	11	17	17
2400	8	10	10	10	18	15
Total	230		314		372	

As seen in Figures 3-2 through 3-4, the raw frequencies of hourly events are quite variable. Even the "smoothed" data exhibits some variablity but trends are more evident with the 3-hour moving average. A casual glance at the data indicates that Brownsville tended to receive greater frequencies of measureable events in the early morning while at both Galveston and Lake Charles the

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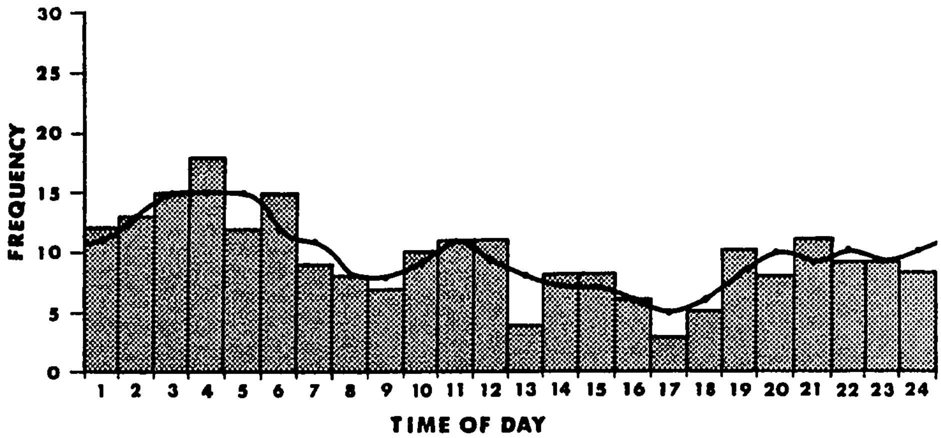

Figure 3-2 January diurnal precipitation frequencies for Brownsville, TX, 1951-60.

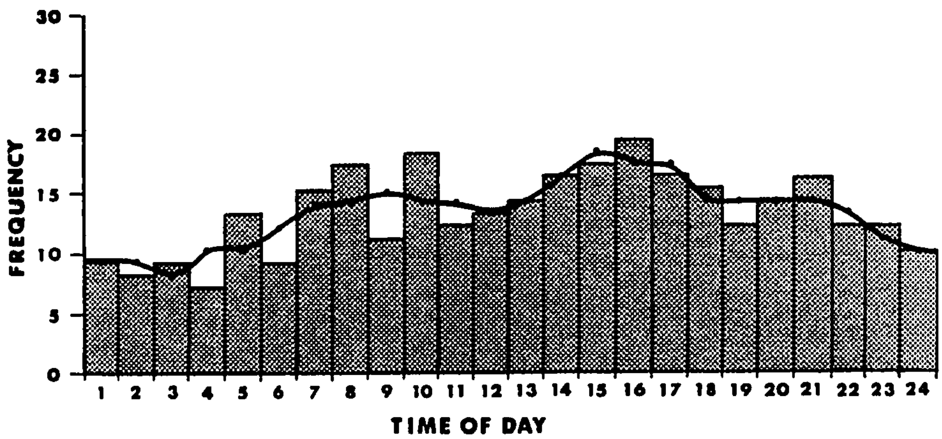

Figure 3-3 January diurnal precipitation frequencies for Galveston, TX, 1951-60.

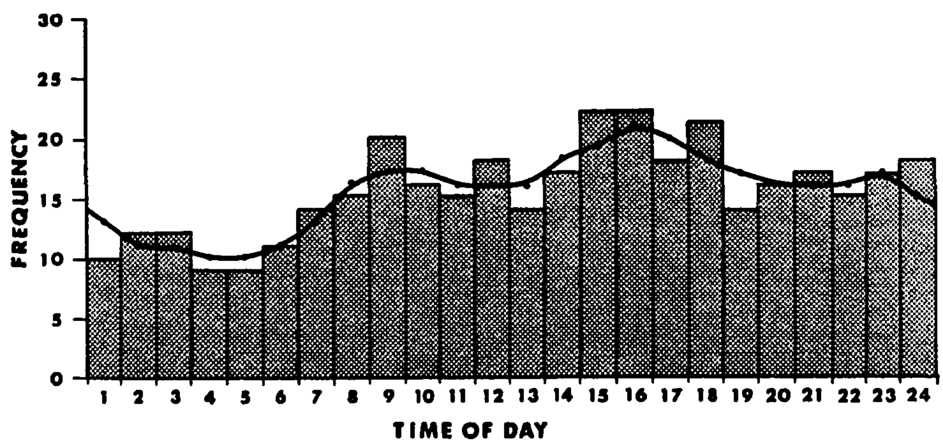

Figure 3-4 January diurnal precipitation frequencies for Lake Charles, LA, 1951-60.

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events were more common during the daylight hours, especially in the afternoon. Another difference between the stations is that Brownsville had much fewer hours of rainfall than did both Galveston and Lake Charles (230 at Brownsville, 314 at Galveston and 372 at Lake Charles). The greater frequency of hourly events at Galveston and Lake Charles is not surprising because these two locations are in a better position to receive ample supplies of Gulf moisture. Onshore flow at Brownsville only occurs with easterly winds which are not as prevalent as southerly winds in the winter months, especially in mild winters like in the 1950's. A southerly wind at Brownsville brings air across the land surface of Mexico and little rain is likely during such conditions. The tendency for morning rainfall at Brownsville in the 1950's is examined later.

The diurnal patterns for the same three stations for the 1960's show two marked changes (Table 3-2). First of all, the total hours of precipitation increased at all three stations (from 230 to 388 at Brownsville, from 314 to 455 at Galveston and from 372 to 509 at Lake Charles). The other notable change is in the timing of the precipitation events. During the 1950's, both Galveston and Lake Charles had maximums in the afternoon. During the 1960's, Galveston had maximum frequencies around noon while Lake Charles peaked around mid-morning. Brownsville retained its' morning maximum in the 1960's (see Figures 3-5 through 3-7).

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Table 3-2. Frequency of measureable hourly precipitation events during January, 1961-70 at Brownsville, Galveston and Lake Charles.

	BROWNSVILLE		GALVESTON		LAKE CHARLES	
Time	freq	3-hour	freq	3-hour	freq	3-hour
0100	17	18	12	13	21	18
0200	18	18	10	14	14	17
0300	18	18	21	17	15	15
0400	17	18	21	22	17	18
0500	20	18	23	21	22	20
0600	18	20	20	21	21	23
0700	23	22	21	21	27	26
0800	25	23	21	21	29	28
0900	21	22	20	21	29	28
1000	19	19	22	22	26	28
1100	18	17	25	25	28	26
1200	14	15	27	26	25	24
1300	14	15	27	26	20	22
1400	17	15	24	22	21	22
1500	13	12	15	19	24	22
1600	7	11	19	18	21	22
1700	14	10	19	18	21	21
1800	9	11	16	15	21	19
1900	9	8	11	15	16	18
2000	7	11	18	16	17	17
2100	16	13	18	18	19	18
2200	17	17	18	16	19	19
2300	18	18	11	15	18	18
2400	19	18	16	13	18	19
Total	388		455		509	

Traditional approaches to diurnal precipitation variability have not treated shifts in patterns over time. Such studies would fail to note the change in both the frequency of events, and even more interesting, the change in the timing of the events from the 1950's to the 1960's. In order to further examine this problem, the data for these stations in the 1970's is displayed in Table 3-4.

In the 1970's, the frequency of hourly events rose again at both Galveston and Lake Charles. Galveston increased from 455 to 507 while Lake Charles went from 509

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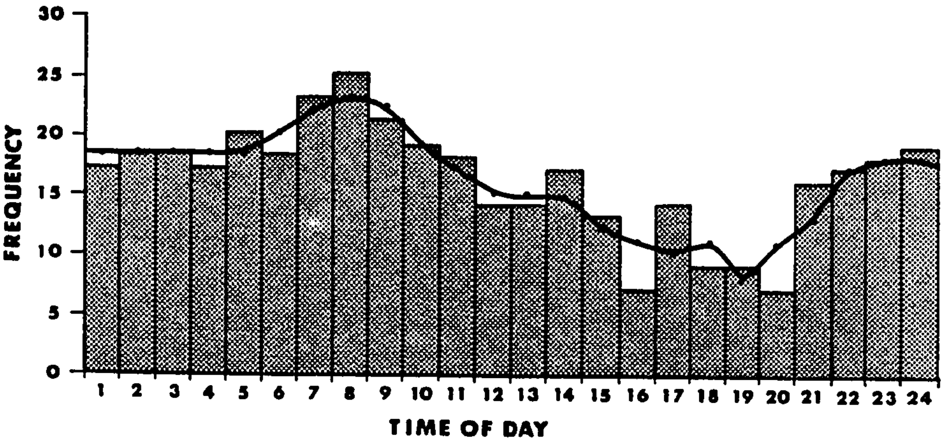

Figure 3-5 January diurnal precipitation frequencies for Brownsville, TX, 1961-70.

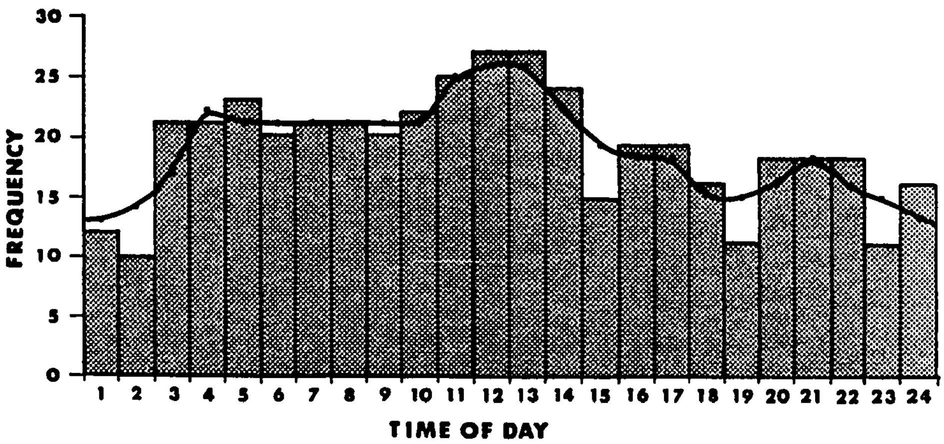

Figure 3-6 January diurnal precipitation frequencies for Galveston, TX, 1961-70.

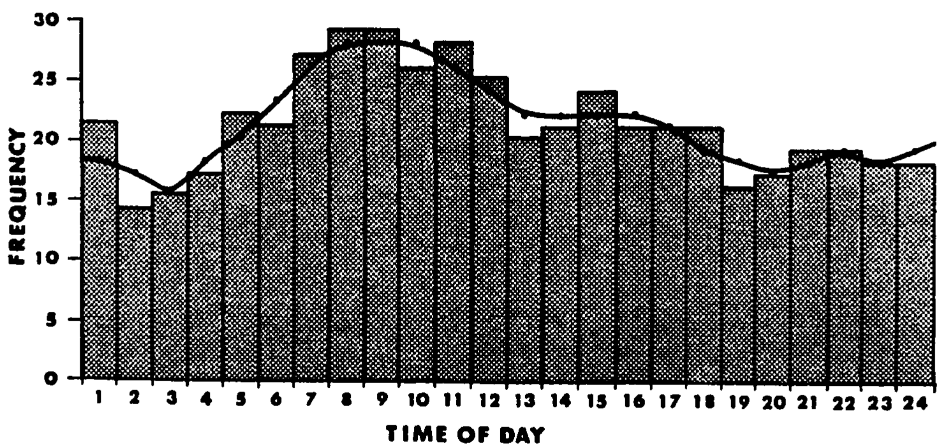

Figure 3-7 January diurnal precipitation frequencies for Lake Charles, LA, 1961-70.

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Table 3-3. Frequency of measureable hourly precipitation events during January, 1971-80 at Brownsville, Galveston and Lake Charles.

	BROWNSVILLE		GALVESTON		LAKE CHARLES	
Time	freq	3-hour	freq	3-hour	freq	3-hour
0100	14	11	21	20	22	21
0200	18	16	23	21	18	21
0300	16	16	20	22	22	21
0400	13	15	23	25	24	23
0500	15	15	31	27	23	25
0600	18	17	26	28	28	26
0700	19	16	28	25	28	30
0800	12	15	22	25	33	33
0900	14	13	24	22	37	36
1000	12	14	21	23	37	34
1100	16	14	23	21	27	31
1200	14	14	18	19	30	29
1300	12	14	17	18	29	28
1400	15	13	19	19	26	26
1500	11	12	21	18	22	23
1600	10	10	15	19	20	22
1700	8	8	21	20	25	25
1800	6	7	24	21	29	26
1900	6	6	18	21	24	25
2000	7	7	21	19	21	23
2100	9	9	17	20	24	23
2200	11	10	21	19	23	23
2300	10	10	18	18	23	23
2400	10	10	15	18	24	23
Total	296		507		616	

hours to 616. At Brownsville, the number of hourly events dropped to 296. Despite these changes in frequencies, the diurnal curves remained remarkably consistant with those of the 1960's (see Figures 3-8 through 3-10). Galveston began to pick up an even earlier maximum in the 1970's, centered around 6 a.m. on the smoothed curve. Data from other first-order stations have shown a similar consistancy between 1960's patterns and 1970's patterns, thus making the lack of data available in the 1970's not as significant a drawback. Based on these similar patterns between the 1960's and 1970's at 7 first-order stations, it can be

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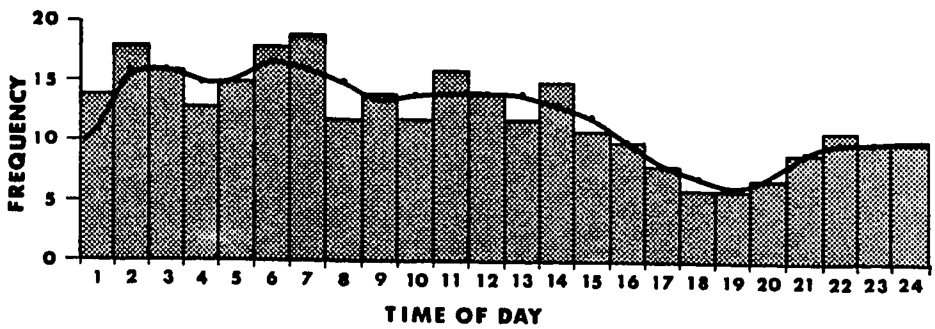

Figure 3-8 January diurnal precipitation frequencies for Brownsville, TX, 1971-80.

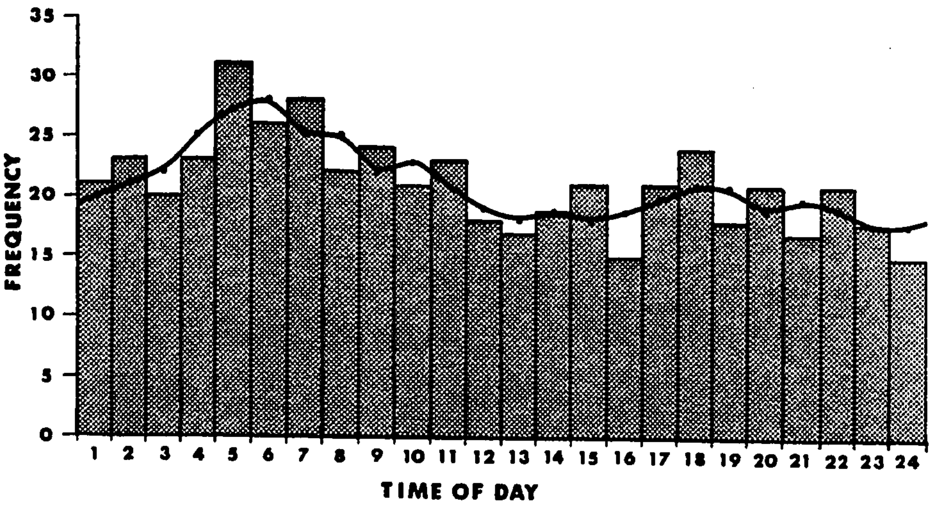

Figure 3-9 January diurnal precipitation frequencies for Galveston, TX, 1971-80.

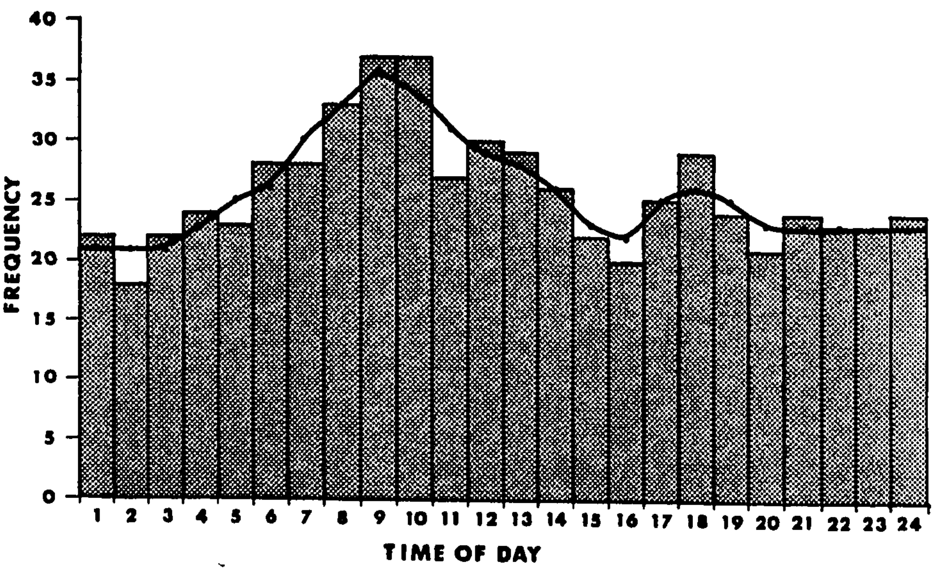

Figure 3-10 January diurnal precipitation frequencies for Lake Charles, LA, 1971-80.

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safely assumed that a more dense network of stations in the 1970's would reveal patterns very similar to those patterns of the 1960's. The other four stations which had similar diurnal patterns between the 1960's and 1970's are New Orleans, Baton Rouge, Shreveport and Corpus Christi.

Figures 3-2 through 3-10 indicate the frequency of the raw data as well as an overlay of the smoothed data. These graphs reveal the peaks but it is important to isolate these peaks in some consistent manner. The isolation of peak hours has been accomplished by identifying all hours with frequencies one or more standard deviations above the mean. In order to make the peaks even more relevant, the smoothed data were used for this analysis which means, therefore, that the smoothed deviations are not as greatly removed from the mean as are the raw deviations. A greater peak is required to emerge as one or more standard deviations above the mean when using this technique.

Figures 3-11 and 3-12 display the peak hours (both above two standard deviations above the mean and between one and two standard deviations above the mean) along a coastal and an inland transect. The geographical patterns which emerge along these transects allow for a visualization of what appears to be trends in the timing of hourly precipitation events as well as a transition zone between morning and afternoon precipitation.

During the 1950's (Figure 3-11a), it is apparent that there is a southwest to northeast transition from morning

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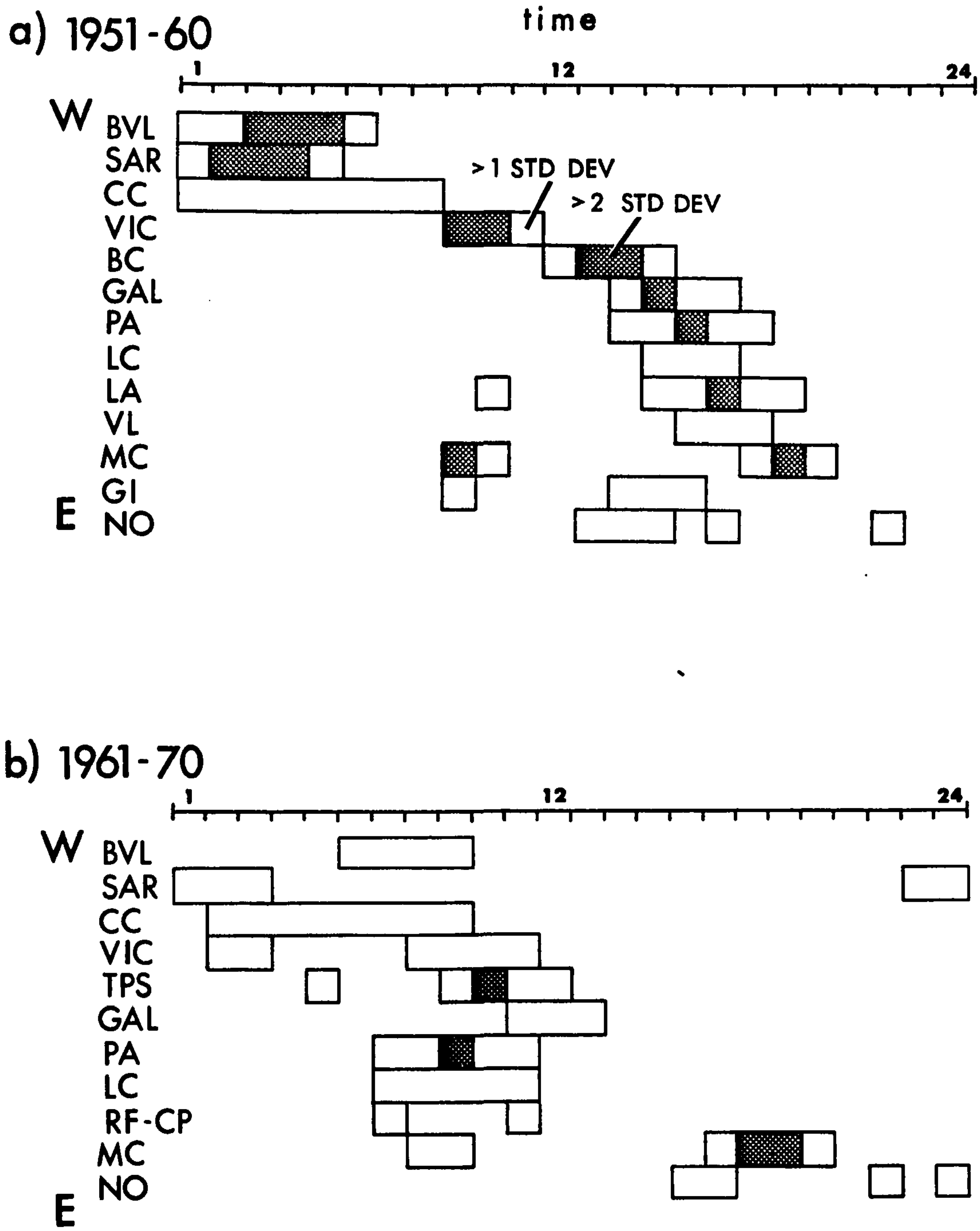

Figures 3-11a and 3-11b Coastal transect indicating hours of precipitation peaks equal to or greater than one standard deviation above the local mean frequency of hourly precipitation events. (3-11a indicates the 1951-60 pattern while 3-11b indicates the 1961-70 pattern)

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to afternoon peaks along the coast. Brownsville, Sarita and Corpus Christi all have peak hours before 9 a.m. Victoria appears to be in a transitional location with peaks greater than 2 standard deviations above the mean at both 9 and 10 a.m. From Bay City, Texas to Vermillion Lock in Louisiana, peaks become evident later in the day as significant peak hours (those greater than or equal to 2 standard deviations above the mean) shift from 1 p.m. and 2 p.m. at Bay City, to 3 p.m. at Galveston, 4 p.m. at Port Arthur, and to 5 p.m. at Lake Arthur. At Morgan City, Grand Isle and New Orleans, the patterns are more variable but the bulk of the peak hours are in the afternoon.

In the 1960's, along the coastal transect (Figure 3-11b), areas as far east as Catfish Point-Rockefeller Wildlife Refuge in Louisiana had peaks in the morning. Only Morgan City and New Orleans had afternoon and evening peaks. The transition was sharp as no station tended to bridge the gap between morning and afternoon peaks.

The inland transect during the 1950's (Figure 3-12a) reveals a trend for morning rain in the west and afternoon rain in the east but the pattern is less well defined and Darnell, Louisiana in the northeastern part of the study area reverts to an early morning peak (2 a.m.). No distinct transition zone is apparent along the inland transect of the 1950's.

Inland, during the 1960's (Figure 3-12b), the pattern remained very similar to that of the 1950's. Both Nacogdoches, Texas and Keithville, Louisiana had more of a

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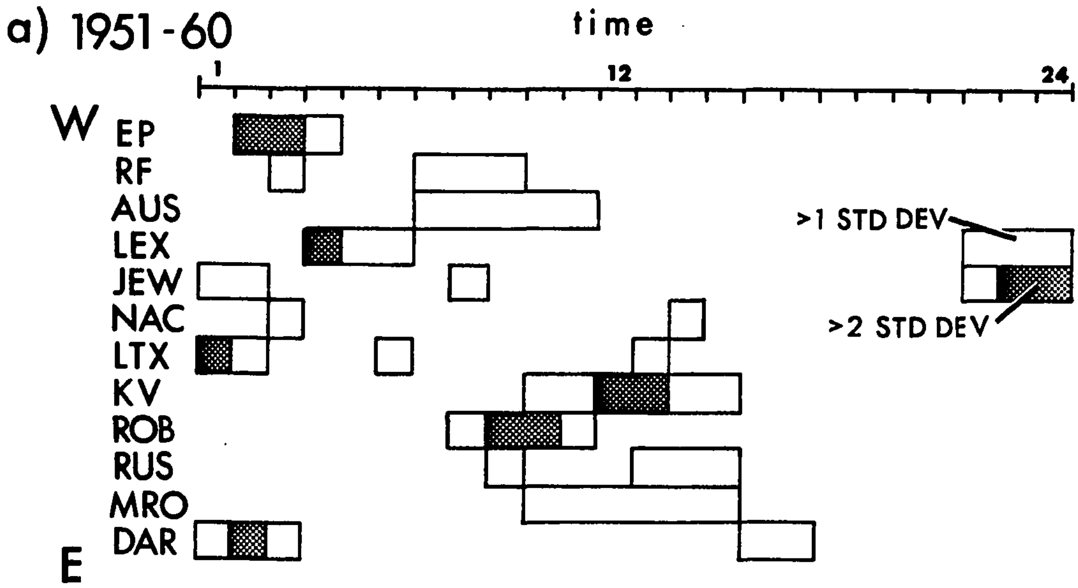

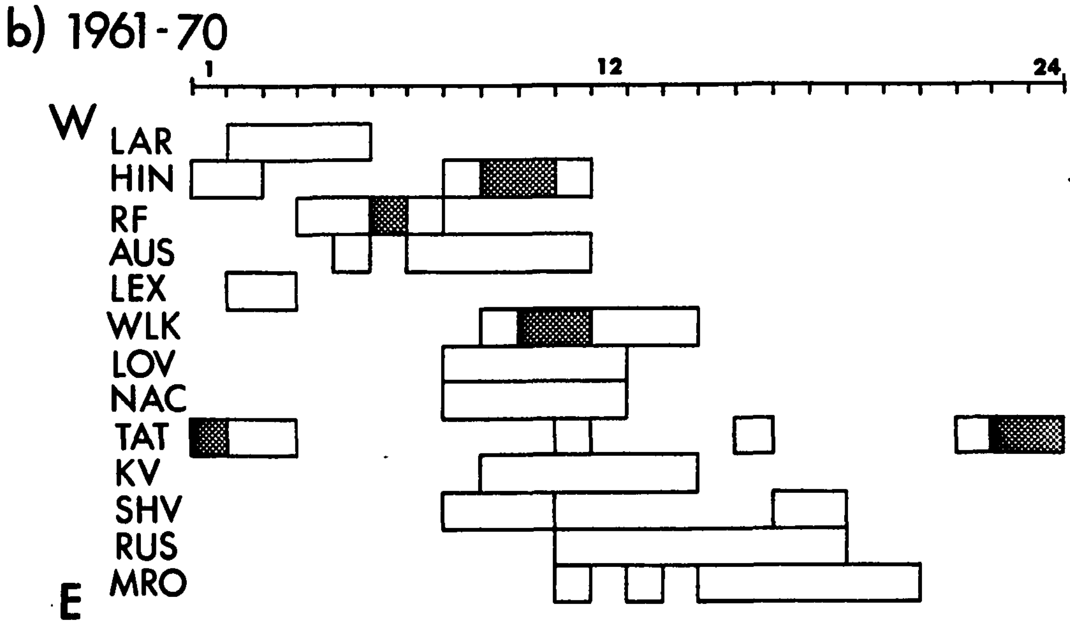

Figures 3-12a and 3-12b Inland transect indicating hours of precipitation peaks equal to or greater than one standard deviation above the local mean frequency of hourly precipitation events. (3-12a indicates the 1951-60 pattern while 3-12b indicates the 1961-70 pattern)

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morning peak in the 1960's while Monroe and Ruston became more oriented towards afternoon events. No distinct transition zone was apparent in the 1960's along the inland transect but the tendency for morning precipitation in the west and afternoon precipitation in the east continued.

Based on the data displayed in Figures 3-11 and 3-12, there is a trend for morning rainfall in the southwestern and western part of the study area, and for afternoon rainfall in the eastern sections. A sharp transition zone appears along the coast, but does not manifest itself along the northern and western part of the study area. It also appears that the zone of morning rainfall and the coastal transition zone shifted east in the 1960's. In order to further locate and visualize the patterns geographically, methods for the mapping these hourly patterns have been devised and the procedures and results of these methods are described in the following chapter.

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CHAPTER IV

THE GEOGRAPHIC DISTRIBUTION OF HOURLY PRECIPITATION PATTERNS

Two methods of mapping diurnal patterns have been chosen. The first is a very simple procedure which identifies locations that had the majority of their peak hours at or before 1200 CST or after 1200 CST, as defined in Chapter Three. The second mapping procedure makes use of correlation field analysis.

Mapping of Peak Hours

In the first procedure, the plot of the data reveals distinct patterns associated with locations with pre and post 1200 CST precipitation patterns (Figures 4-1, 4-2). In the 1950's, Figure 4-1, all of southern Texas from Brownsville to Victoria to Eagle Pass and Austin had morning precipitation maxima (0100 to 1200 CST). A narrow band of morning precipitation also extended northeastward through Conroe, Shepherd, Rockland and Latex and into Louisiana at Robson, Bernice, Darnell and Harrisonburg Dam. To the north of this band, both Lovelady and Jewett had the majority of their peak hours after 1200 CST. South of this band of morning precipitation was an area of post 1200 CST maximums from Bay City, Texas, through the Houston-Galveston area, as far north as Ruston, Lousiana and eastward to Clinton, French Settlement and New Orleans.

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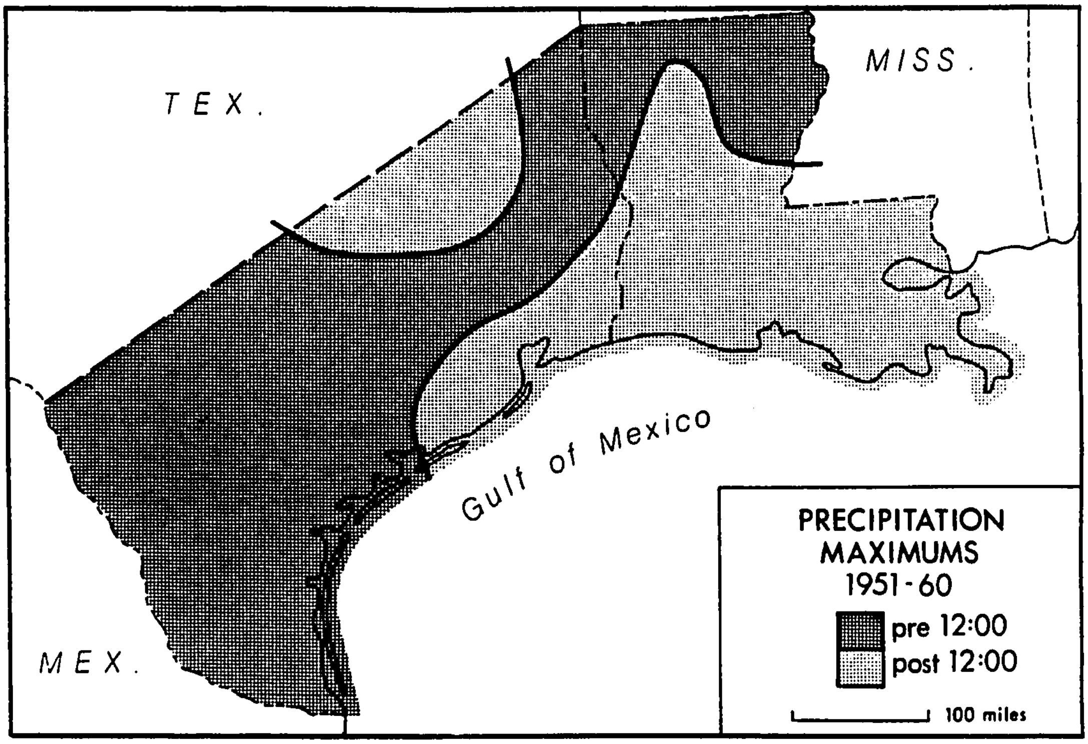

Figure 4-1 Morning and afternoon precipitation maximums based on peaks in the smoothed distribution of hourly precipitation events for the 1951-60 period.

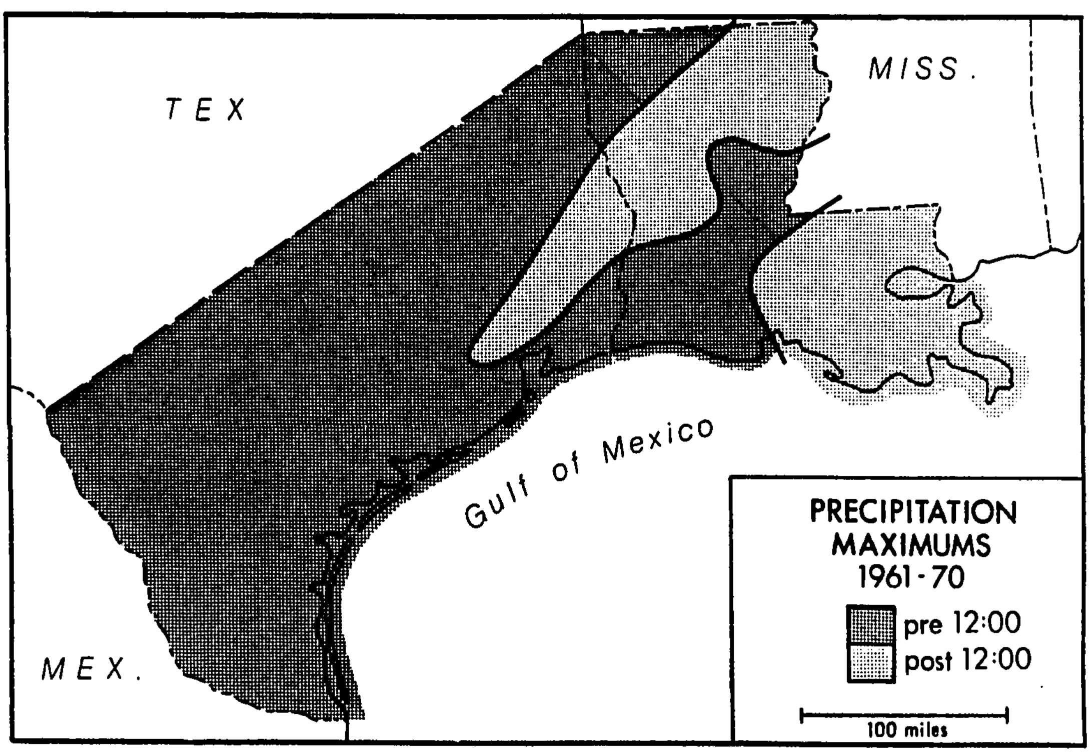

Figure 4-2 Morning and afternoon precipitation maximums based on peaks in the smoothed distribution of hourly precipitation events for the 1961-70 period.

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The intriguing aspect of this pattern is the band of morning precipitation which extends northeastward through eastern Texas.

In the 1960's, as revealed in Figure 4-2, a similar band of morning precipitation existed from the Galveston area, northeastward to Lake Charles (with all five peak hours between 0700 and 1200 CST) and to the Lettsworth-Vidalia area. Another region of morning maximums was found from Shreveport, southeastward to Pollock and Olla. Strong afternoon and evening maximums existed from Opelousas (all five peak hours after 1300 CST) to Clinton (five of six after 1300 CST) and New Orleans (all four peak hours after 1300 CST). Every station in Texas, with the exception of Houston and Kountze, had the majority of peak hours between 0100 and 1200 CST in the 1960's.

Correlation Fields

The patterns revealed by the above method are interesting but a method of mapping which would be more statistically rigorous was desired. The method chosen for this analysis was to determine correlation fields based on the smoothed data. The smoothed frequency of hourly events at each location for both the 1950's and 1960's were correlated with all other stations.

Eighteen correlation fields have been constructed for the 1950's, while 19 were determined for the 1960's. The maps themselves depict those areas which were correlated at both the 99% and the 95% confidence level with any of the

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selected stations. For example, in Figure 4-3, those stations which had diurnal frequencies of hourly precipitation which were related significantly to the pattern at Randolph Field (San Antonio) are plotted.

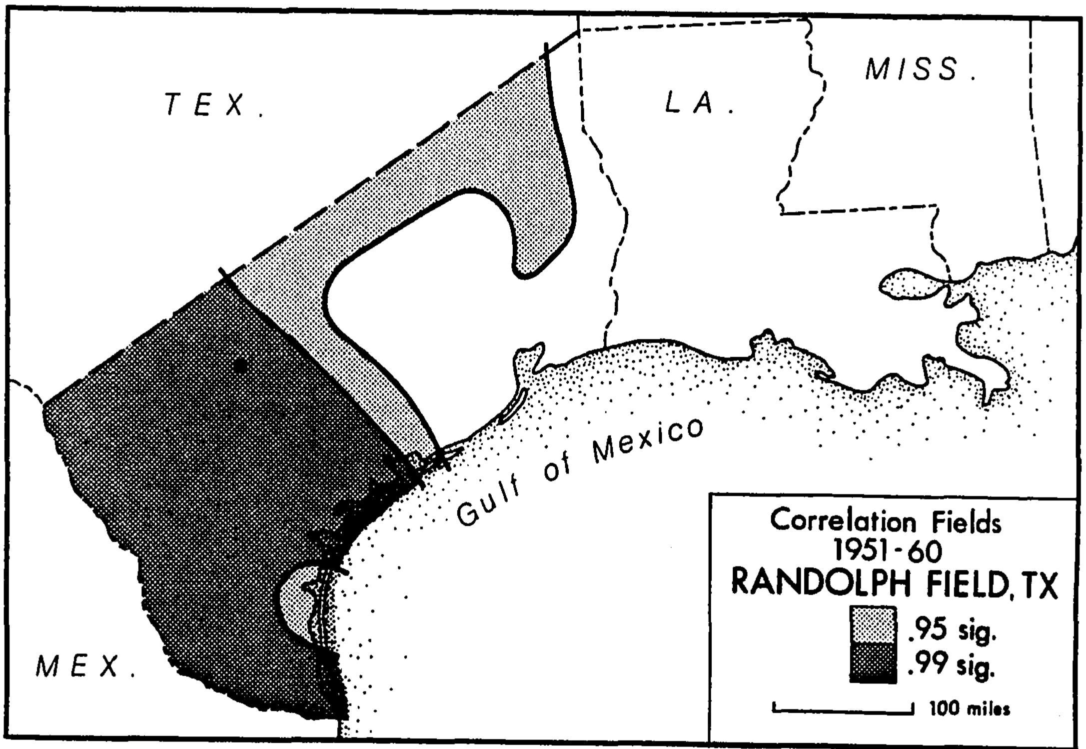

Figure 4-3 Correlation field for Randolph Field, TX, 1951-60.

Correlation Fields in the 1950's

Randolph Field, which during the 1950's had a strong morning pattern (all four peak hours before 1000 CST) had a correlation field which included 99% level relationships from Brownsville to Eagle Pass and northward to Cheapside and Victoria. To the north, Austin, Jewett, Nacogdoches and Rockland all had relationships with Randolph Field at the 95% level. All of the rest of the study area had either no relationship with the Randolph Field pattern or had a significantly inverse relationship. Negative

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relationships significant at the 99% level included Lake Charles, Kountze, Port Arthur, Lake Arthur, LA, Lettsworth, Batchelor and New Orleans. Negative relationships significant at the 95% level included Montgomery, LA, Baton Rouge, and as far west as Galveston. Sarita, Texas had a correlation of .45, significant at the 95% level.

Laredo (Figure 4-4), another location with a morning precipitation maximum (all five peak hours before 1200 CST), had 99% signicant relationships with Brownsville, Zapata and Eagle Pass, northeastward through Hindes, Randolph Field and Lexington. Relationships significant at the 95% level were located at Sarita, Cheapside and as far northeastward as Jewett. Again, the significant negative relationships were found in Louisiana but also as far west as William Harris Reservoir, just to the southwest of Houston.

At Eagle Pass, where all three peak hours occurred between 0200 and 0400 CST, a pronounced southwest to northeast orientation is revealed in the correlation field (Figure 4-5). South and west of Sarita and Randolph Field, all stations were correlated at the 99% level but locations significantly related at this level were also found at Somerville, Shepherd and Nacogdoches. Patterns significant at the 95% level included those at Victoria, Cheapside, and Darnell in northeastern Louisiana. Correlations between .30 and .40, levels just less than the significant range, are found just to the north and east of this narrow southwest-northeast band.

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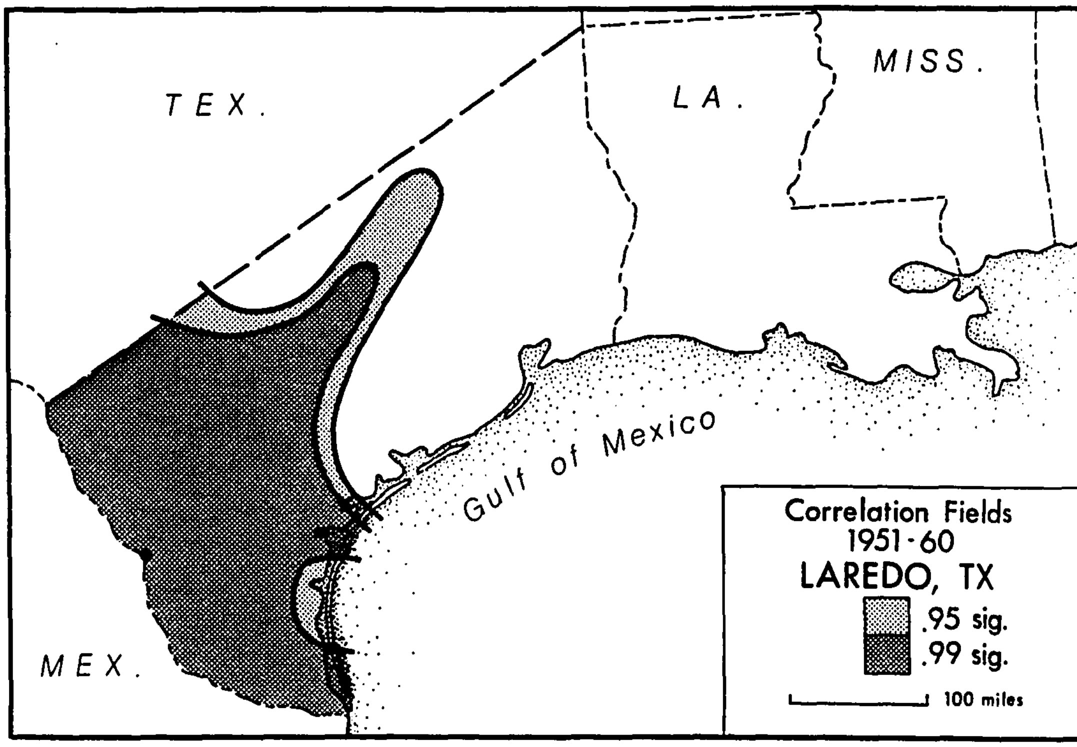

Figure 4-4 Correlation field for Laredo, TX, 1951-60.

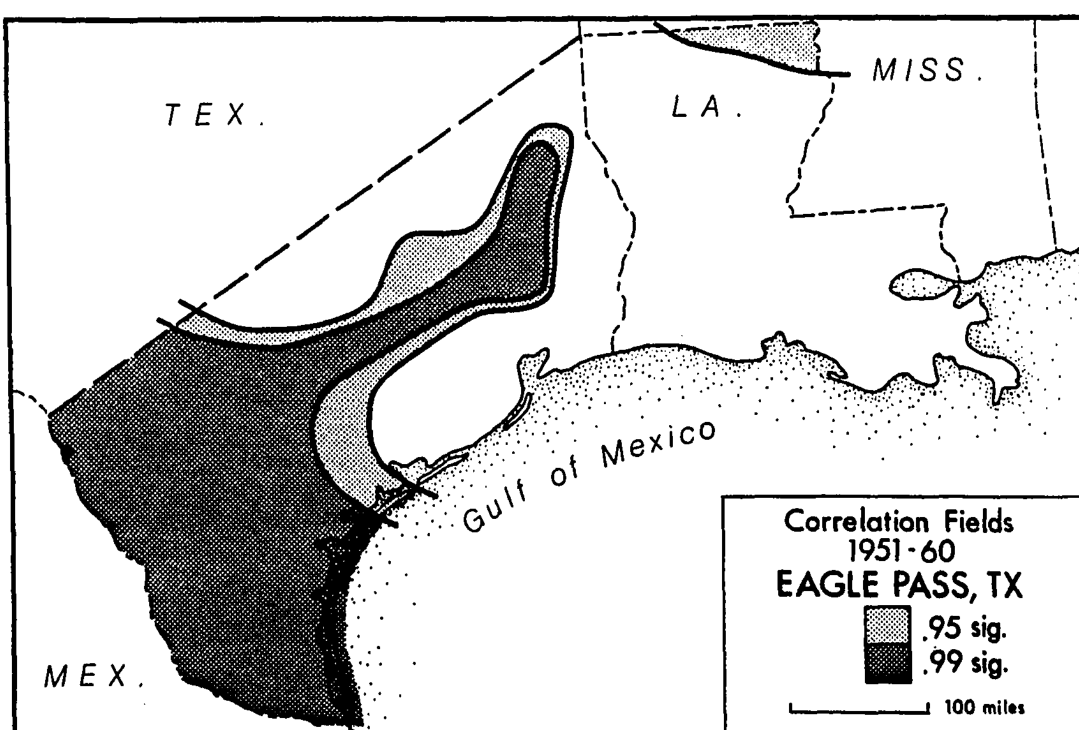

Figure 4-5 Correlation field for Eagle Pass, TX, 1951-60.

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Similar southwest to northeast bands are evident in the correlation fields of Brownsville, Sarita, Cheapside, Calhoun, Somerville, Shepherd, and Nacogdoches in Texas as well as in the fields of Robson and Monroe in northern Louisiana (Figures 4-6 through 4-14), all of which have morning maxima.

The correlation field for Houston (Figure 4-15) appears to be a transition from the morning precipitation associated with the southwest-northeast band from southern Texas to northern Louisiana. Diurnal patterns significant at the 99% level included Calhoun, Galveston, Rockland, Leesville, LA, Montgomery, Opelousas, Vermillion Lock, Grand Isle and French Settlement.

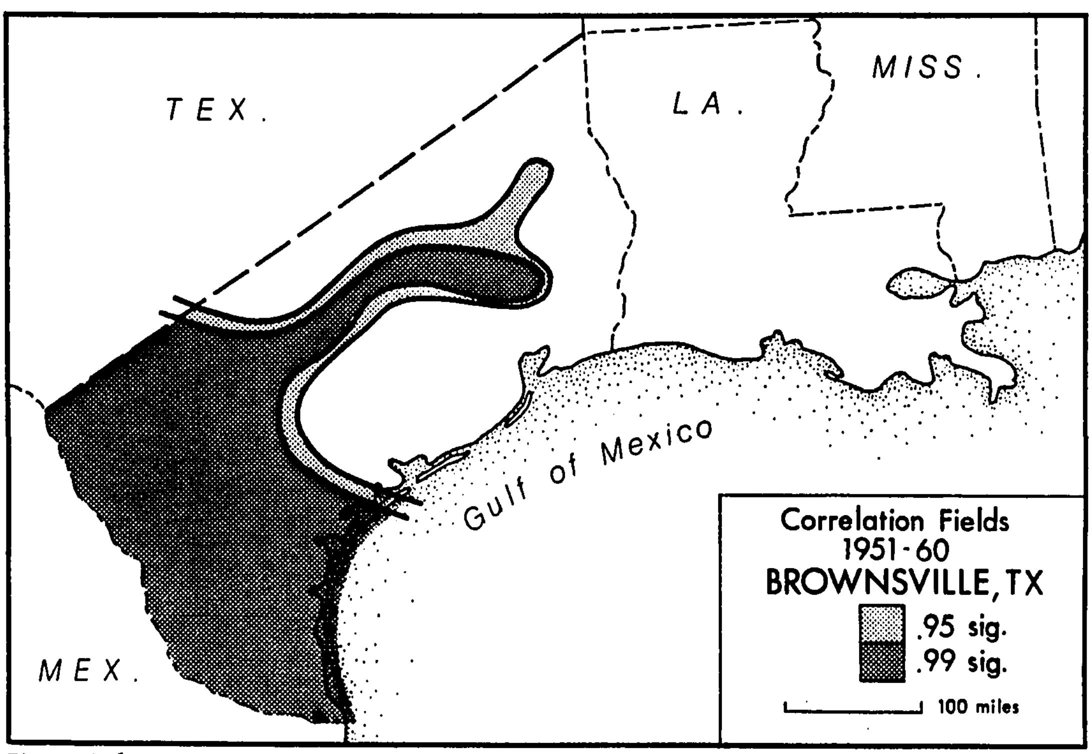

Figure 4-6 Correlation field for Brownsville, TX, 1951-60.

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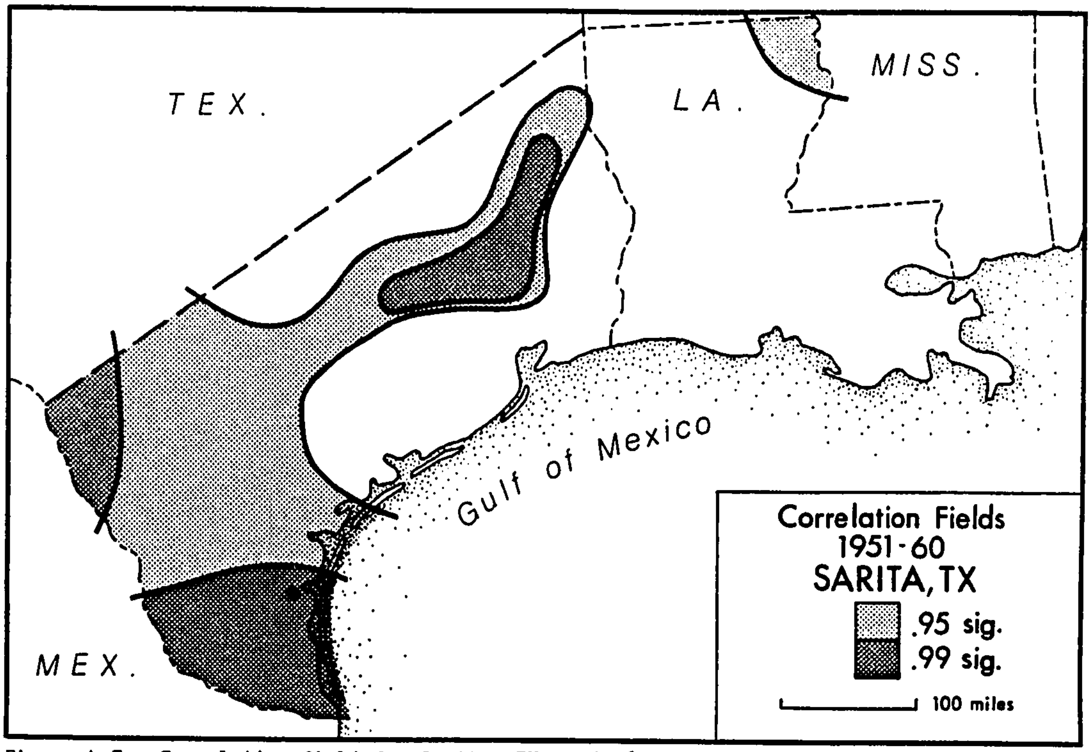

Figure 4-7 Correlation field for Sarita, TX, 1951-60.

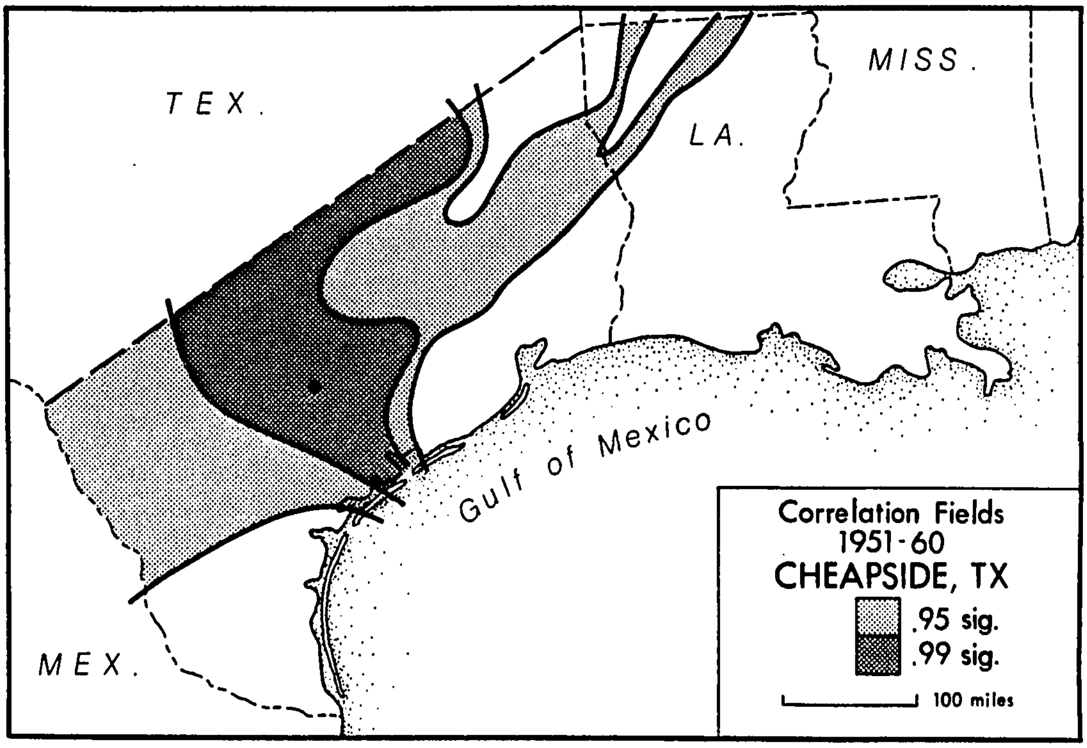

Figure 4-8 Correlation field for Cheapside, TX, 1951-60.

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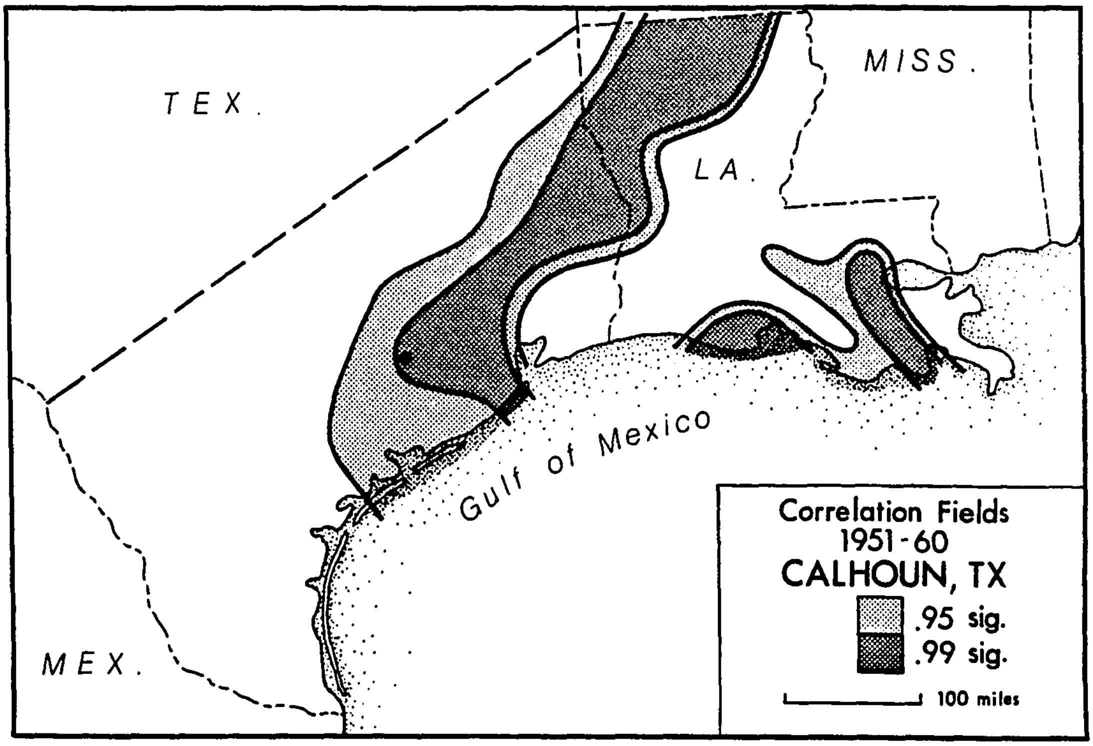

Figure 4-9 Correlation field for Calhoun, TX, 1951-60.

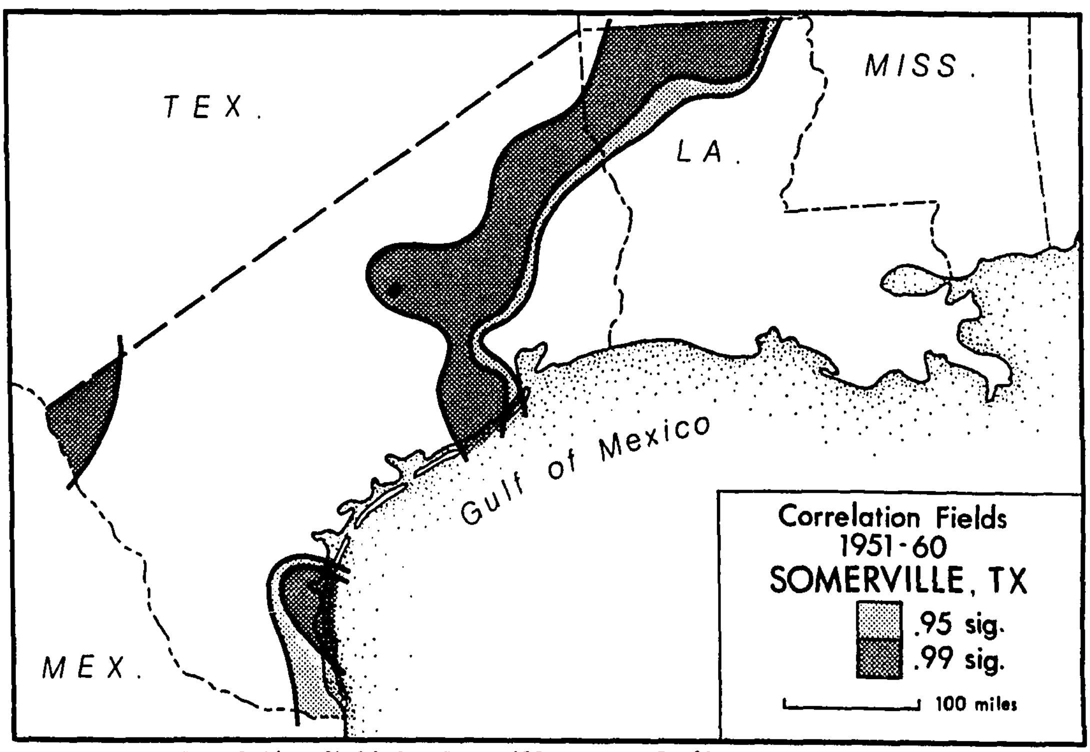

Figure 4-10 Correlation field for Somerville, TX, 1951-60.

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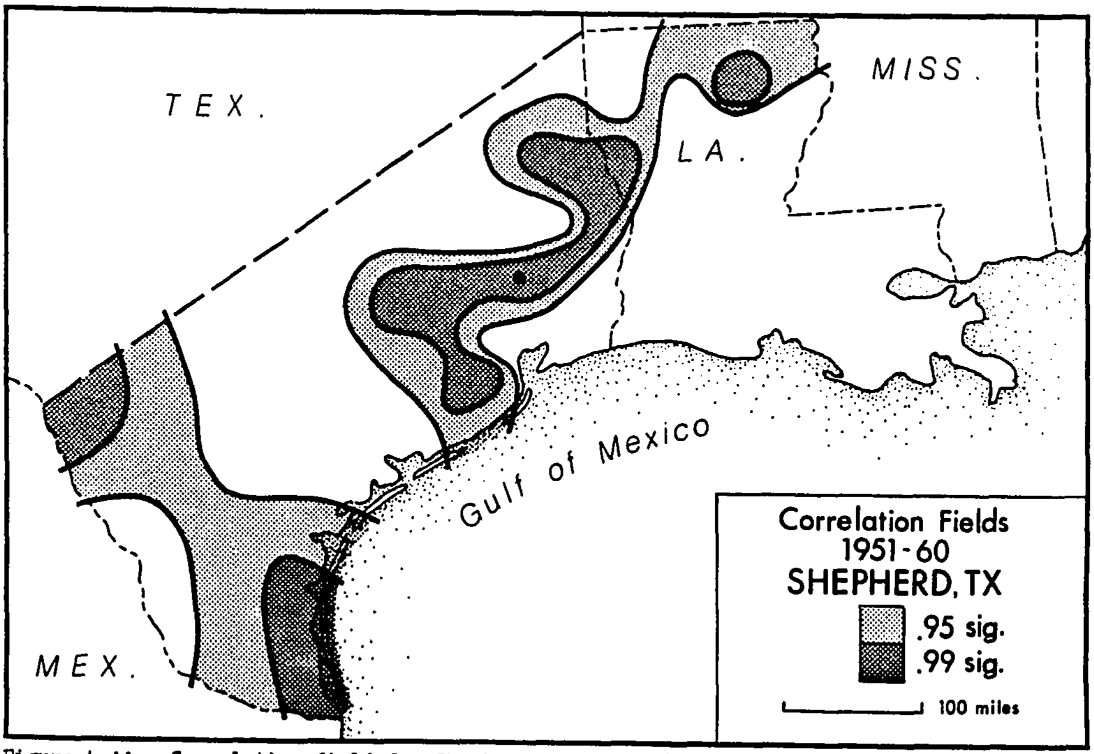

Figure 4-11 Correlation field for Shepherd, TX, 1951-60.

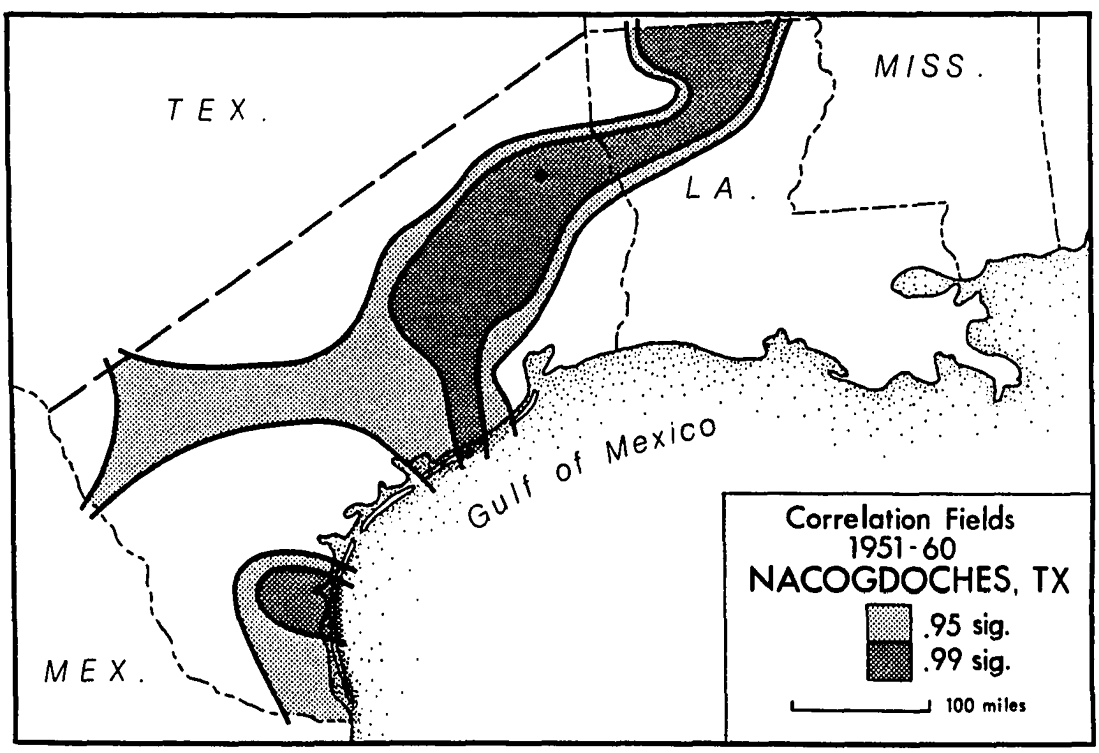

Figure 4-12 Correlation field for Nacogdoches, TX, 1951-60.

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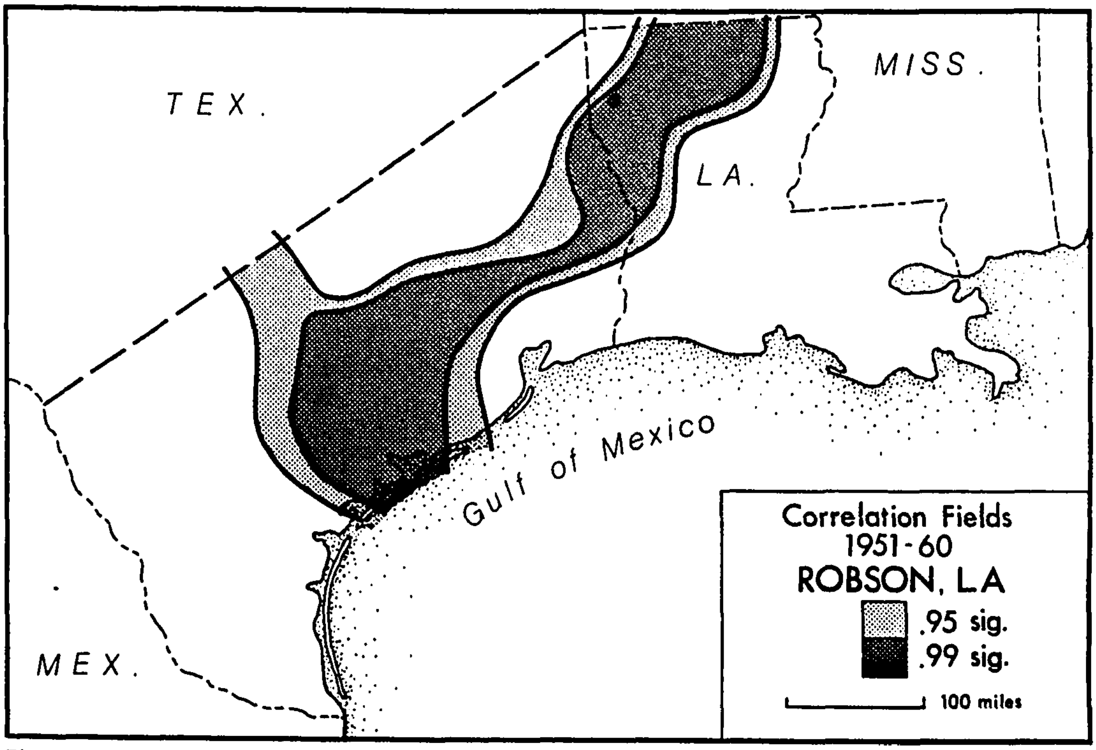

Figure 4-13 Correlation field for Robson, LA, 1951-60.

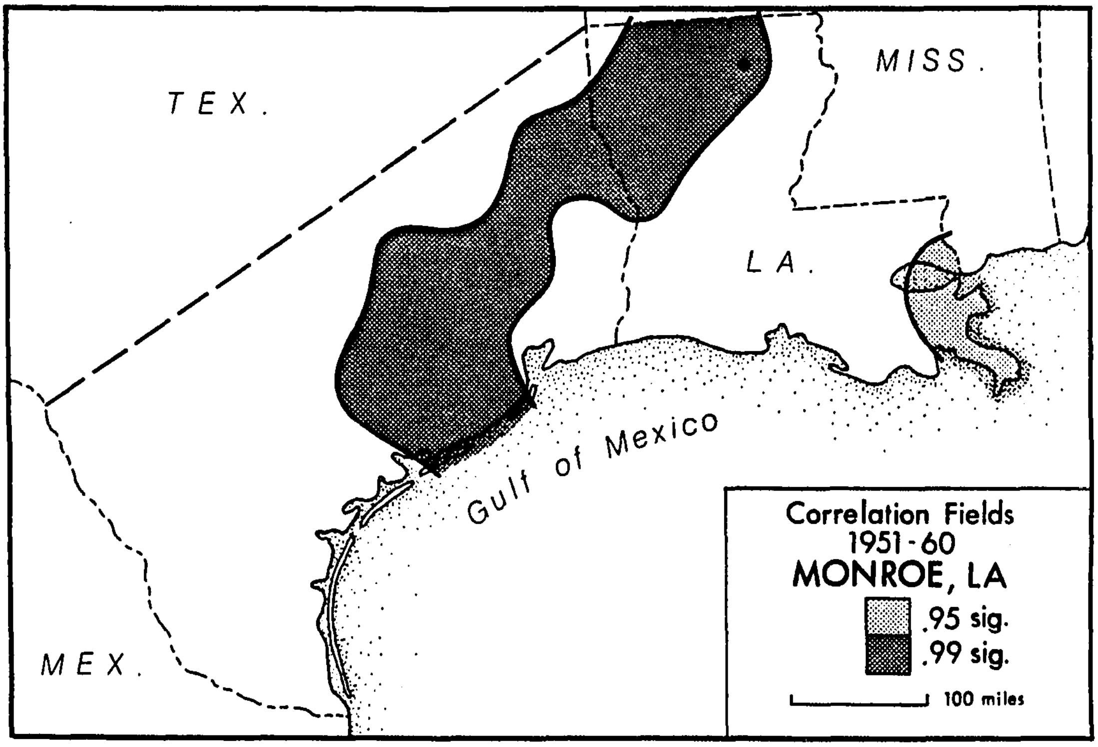

Figure 4-14 Correlation field for Monroe, LA, 1951-60.

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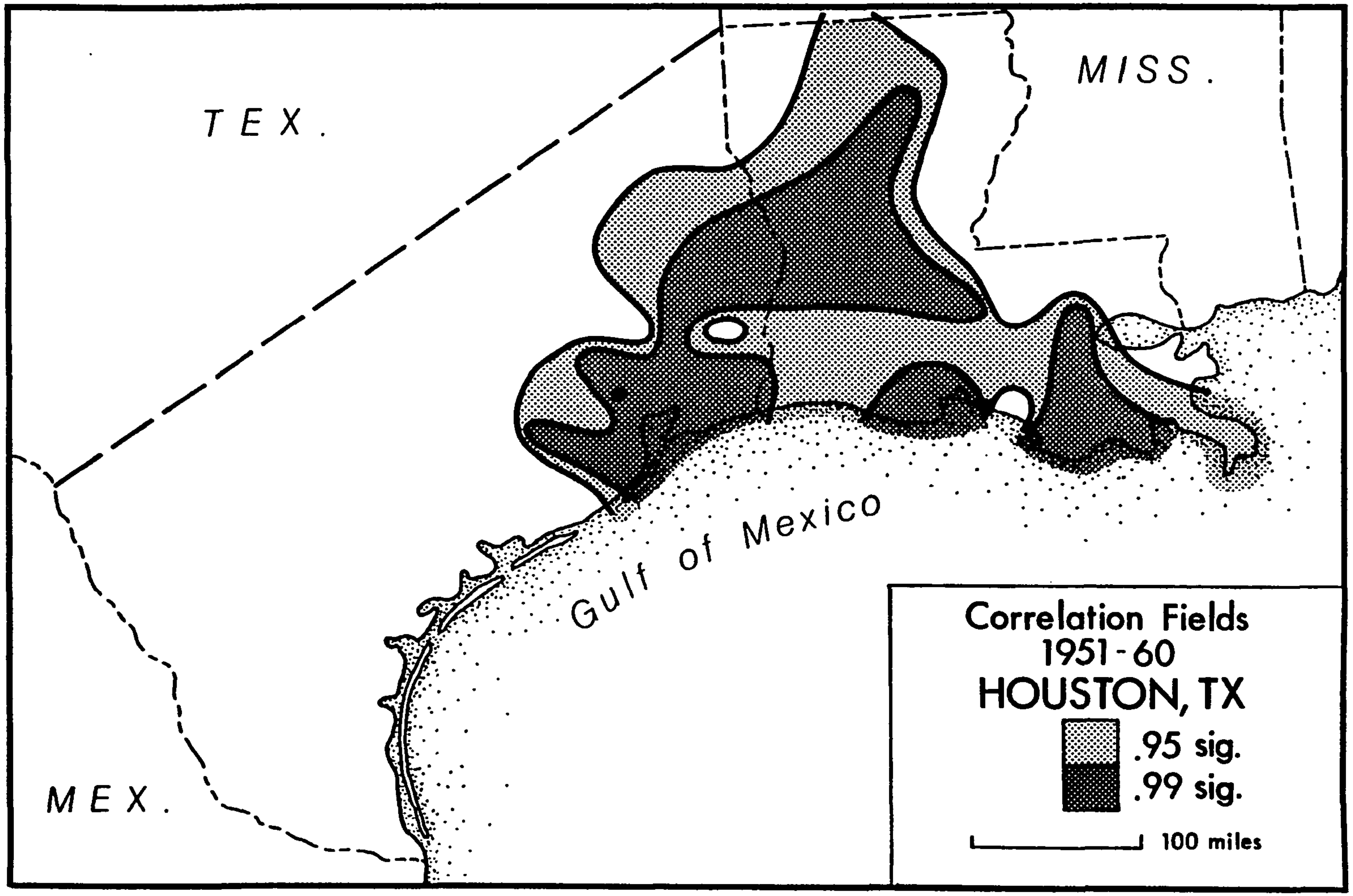

Figure 4-15 Correlation field for Houston, TX, 1951-60.

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The correlation fields for Galveston, Port Arthur and Lake Charles (Figures 4-16 through 4-18), all afternoon maximums, are similar. Significant relationships at the 99% level extended from the Houston-Galveston area, east to Lake Charles, northward towards Ruston and southeastward to New Orleans. In all three situations, the Lafayette and Morgan City diurnal patterns were not significantly related.

For Lettsworth (Fig. 4-19), an area from Port Arthur, Lake Charles and Lake Arthur to Batchelor and Baton Rouge, then southeastward to New Orleans was significant at the 99% level. A more coastal orientation is evident in the correlation field for French Settlement (Fig. 4-20).

Two general trends are evident in the correlation fields of the 1950's. Southern Texas, in which morning precipitation patterns were dominant in the 1950's, tended to have significantly related patterns. Northeastward from a San Antonio-Victoria line through Somerville, Shepherd, Nacogdoches and into Louisiana near Robson, Keithville, Monroe and Darnell, a narrow band of morning rainfall existed. The second pattern indicated a tendency for significantly related afternoon patterns from the Houston-Galveston area, eastward towards Baton Rouge and New Orleans as well as northward towards Ruston.

Correlation Fields in the 1960's

A progression of eight maps indicating correlation fields over the entire study area during the 1960's has

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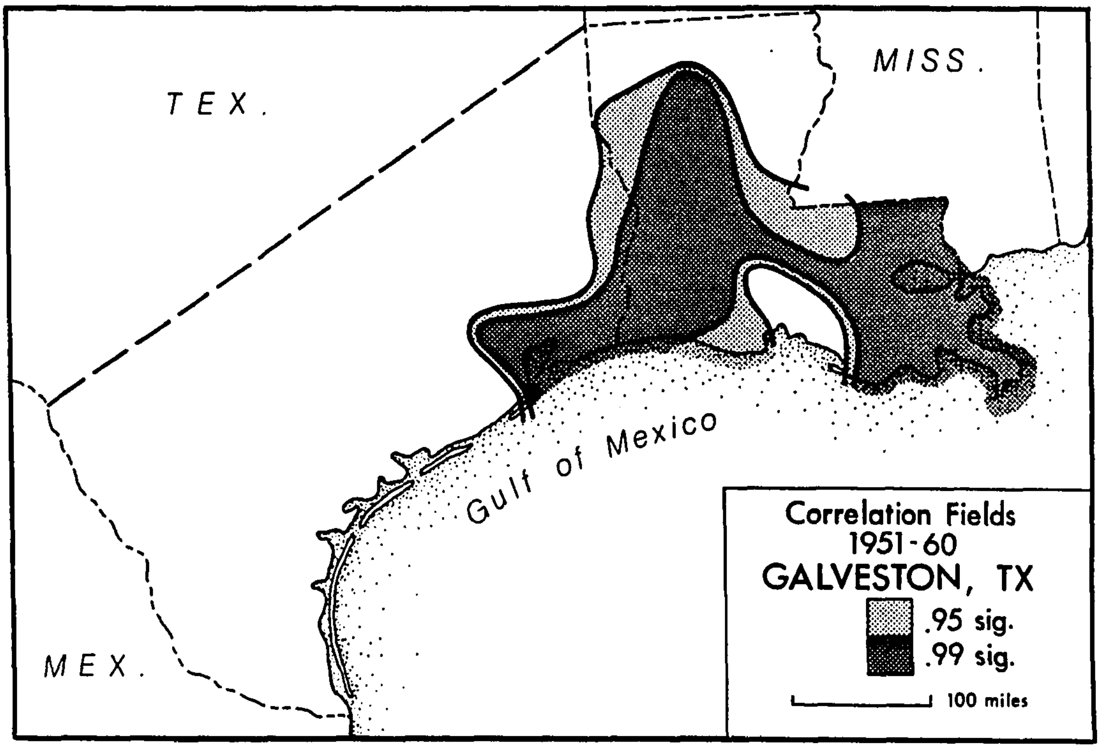

Figure 4-16 Correlation field for Galveston, TX, 1951-60.

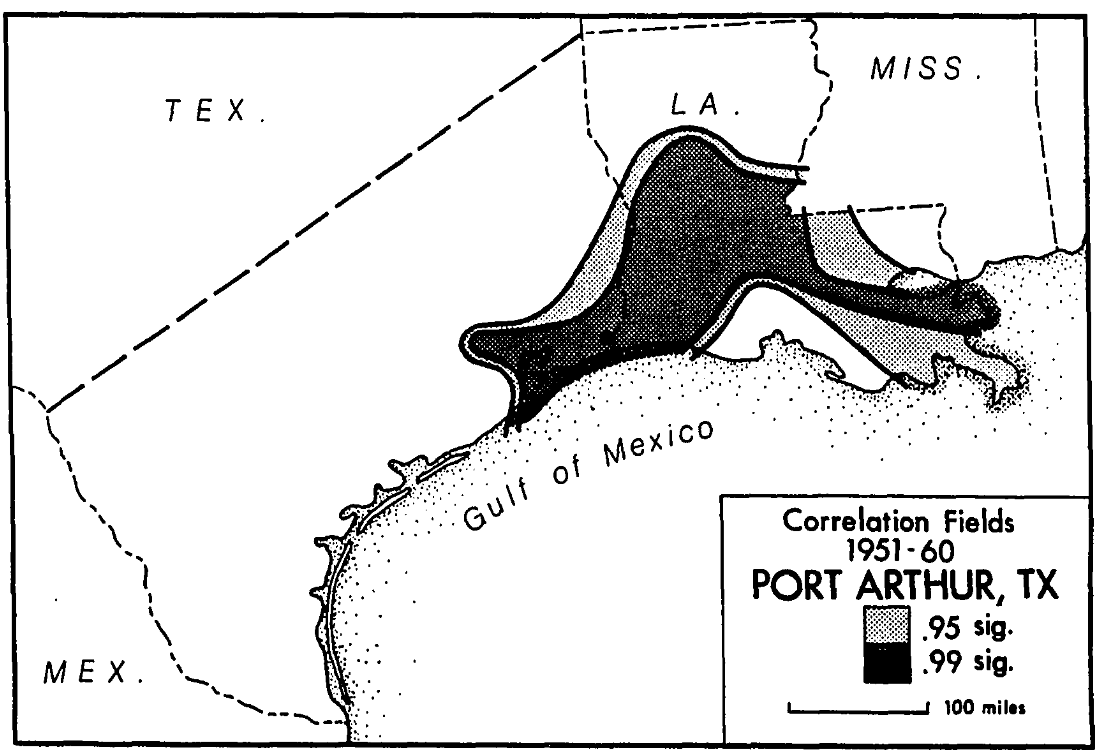

Figure 4-17 Correlation field for Port Arthur, TX, 1951-60.

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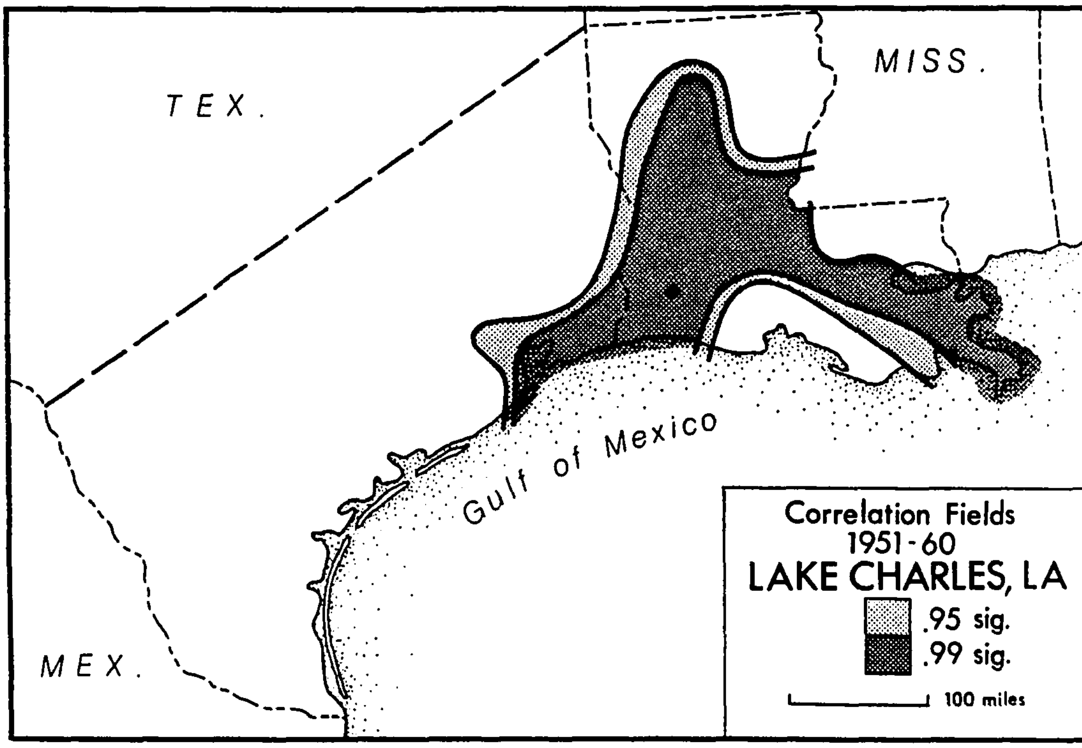

Figure 4-18 Correlation field for Lake Charles, LA, 1951-60.

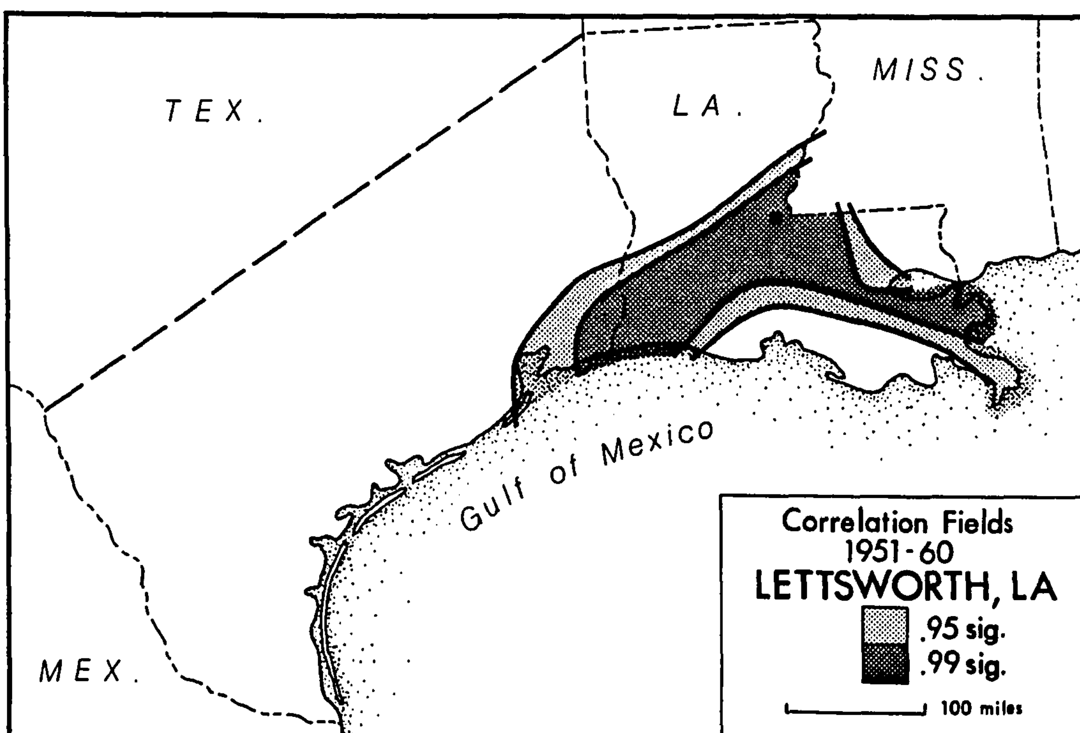

Figure 4-19 Correlation field for Lettsworth, LA, 1951-60.

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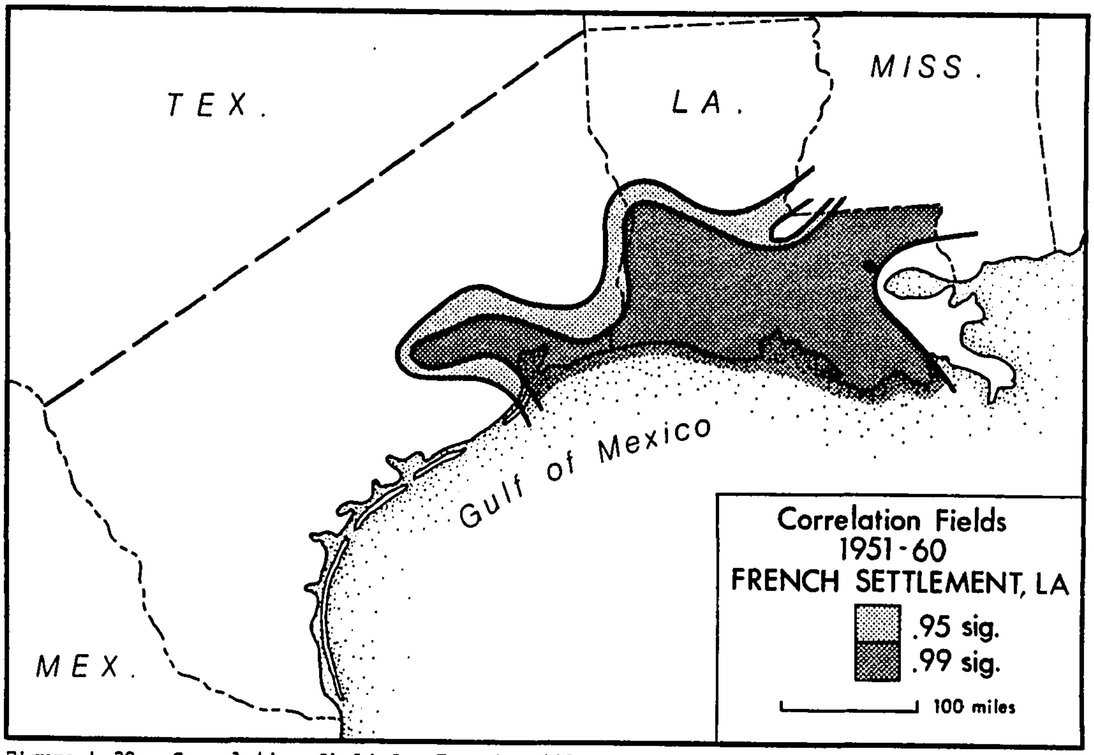

Figure 4-20 Correlation field for French Settlement, LA, 1951-60.

been constructed. The correlation field for Laredo (peak hours from 0200 to 0500 CST) indicates that most of southern Texas had a correlated pattern at the 99% level (Fig. 4-21). Only Benevides failed to be significantly related to the Laredo pattern. Brownsville, Weslaco, Sarita, Corpus Christi, Hindes, and San Antonio were all significant at the 99% level. To the north and east, Victoria and Lexington were significant at the 95% level. Most of the Louisiana stations had significantly negative relationships with the Laredo pattern.

The correlation field for Brownsville (Fig. 4-22) shows a greater northward and eastward orientation. Everywhere south and east of an Austin-Victoria line, with the exception of Benevides, was significant at the 99%

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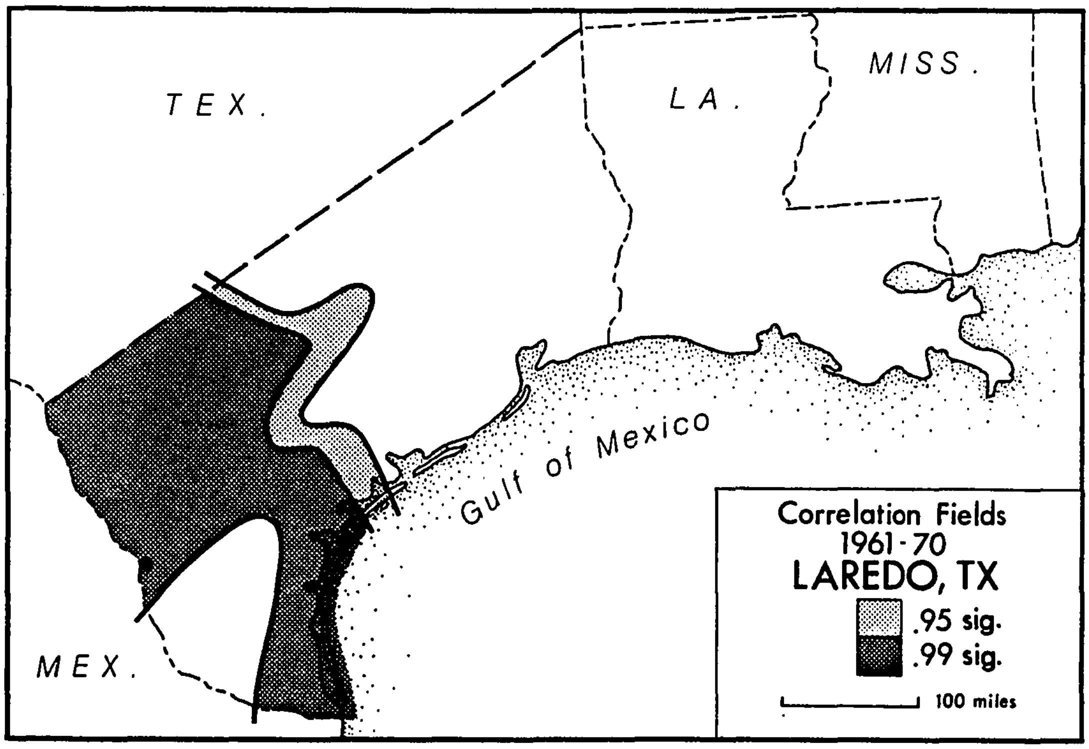

Figure 4-21 Correlation field for Laredo, TX, 1961-70.

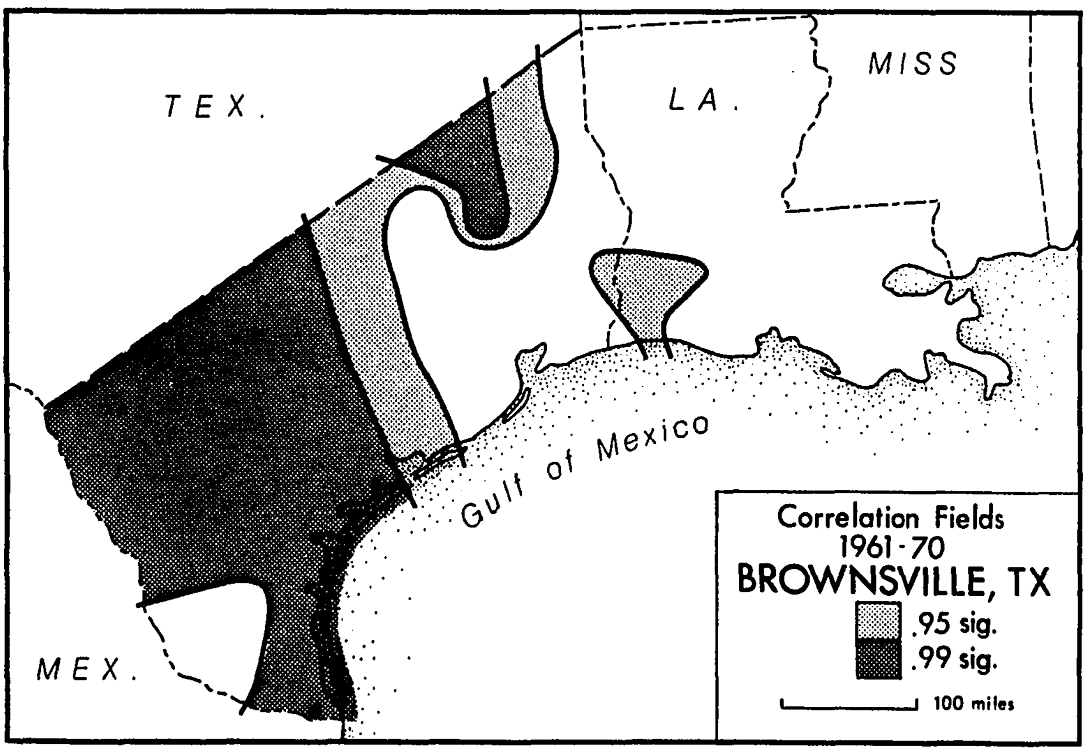

Figure 4-22 Correlation field for Brownsville, TX, 1961-70.

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level. Also significant at the 99% level was Lovelady. At the 95% significant level an interesting pattern begins to emerge. Not only did the pattern shift farther north, but both Bon Wier, Texas and Lake Charles were significantly related at this level. In the 1950's, none of the stations in southern Louisiana were significantly related to the morning peak patterns in southern Texas.

Further evidence of a significant morning peak in the Lake Charles area appears in the Victoria correlation field (Fig. 4-23). In this case, nearly all of Texas is significantly related to a station with a morning maximum (all peak hours beween 0900 and 1100 CST). Bon Weir and Lake Charles have a significant relationship, once again, but this time at the 99% level. Keithville, in northwest Louisiana was related at the 95% level.

Thompsons, just to the south of Houston, has all five of its peak hours before 1200 CST and a new pattern emerges based in this correlation field (Fig. 4-24). Southern Texas is not significantly related to the Thompsons pattern. This is probably because the southern part of Texas tends to have peaks before 0600 CST, while the Thompsons diurnal pattern is centered around 0900 or 1000 CST. In this case, the 99% level correlations extend from Austin and Victoria, northeastward through Lake Charles and Leesville. In northern Louisiana, Shreveport, Ruston, Olla and Pollock were related at the 99% level. A band of 99% level significance extends northeastward from Lake Charles to Lettsworth. While much of northern

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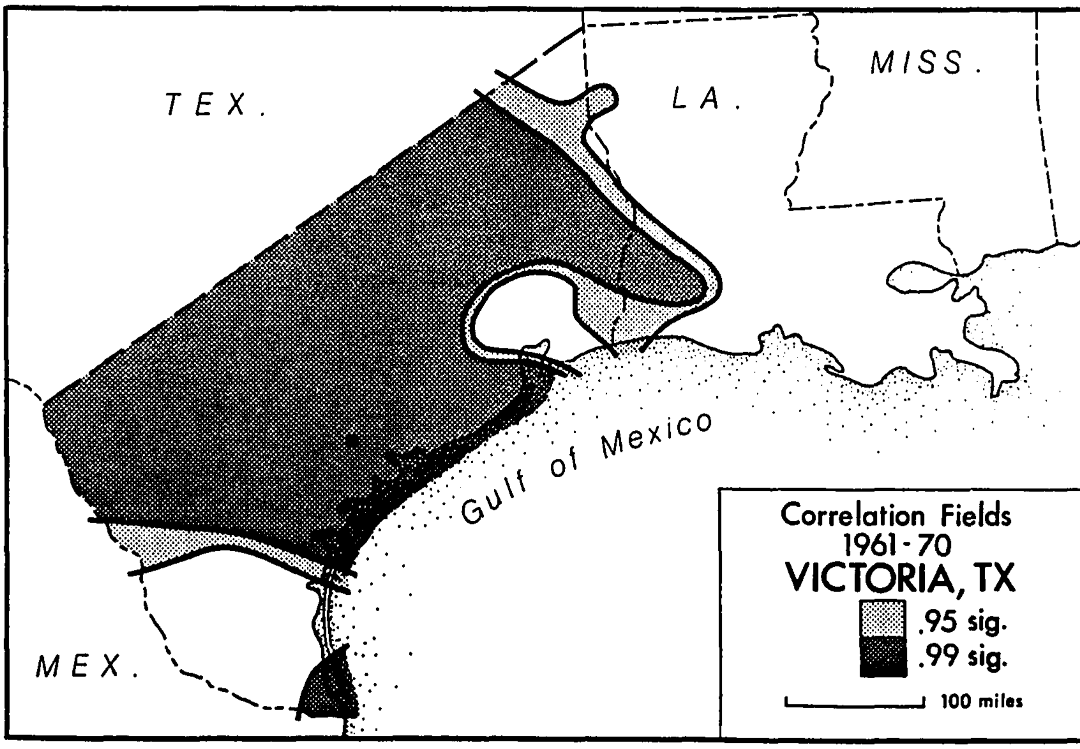

Figure 4-23 Correlation field for Victoria, TX, 1961-70.

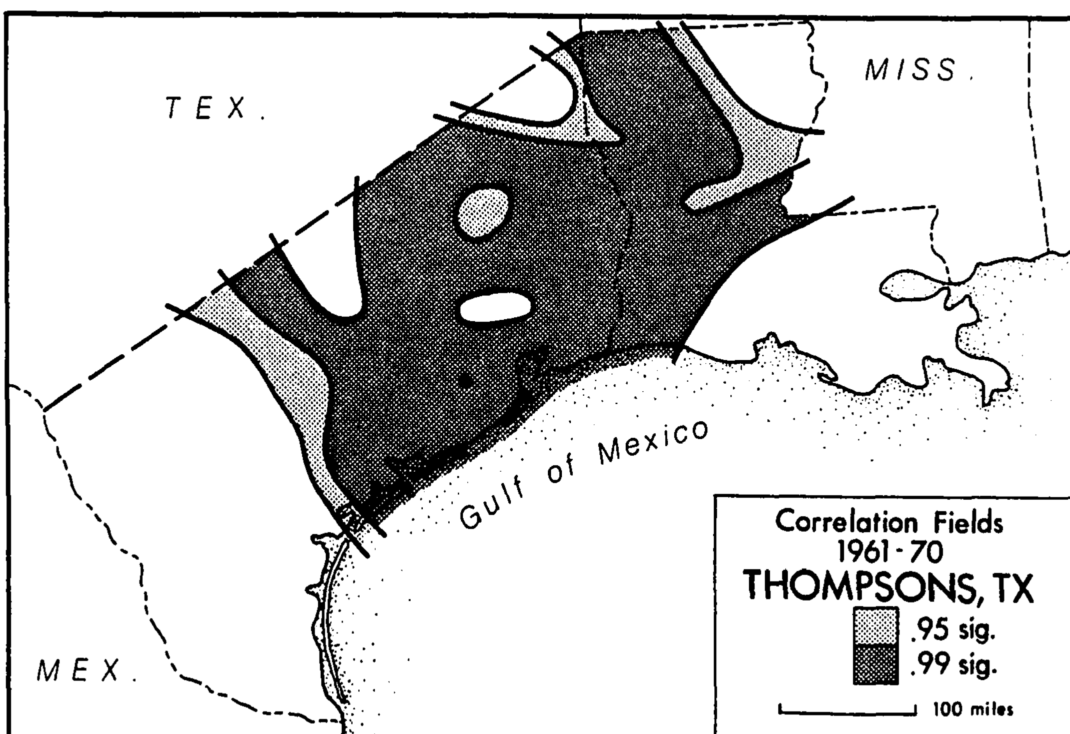

Figure 4-24 Correlation field for Thompsons, TX, 1961-70.

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Louisiana tended to have morning peaks in the 1950's as well, the morning peaks at Lake Charles, Leesville, Port Arthur, and Galveston are quite the inverse of their 1950's diurnal pattern. Even more interesting are the cases of Lettsworth (99% relationship with Thompsons) and Vidalia (95%). It appears that the narrow southwest-northeast band which was in Texas during the 1950's, has shifted south and east to a Lake Charles-Lettsworth line.

Further evidence of this band is shown in the Lake Charles correlation field (Fig. 4-25). Not only is Lettsworth significant at the 99% level, but so is Vidalia. South of this band, insignificant relationships are found and from Lettsworth to Baton Rouge, a distance of about 48 miles, the relationships deteriorate from the .73 a Lettsworth to -.65 at Baton Rouge. North of the band, Harrisonburg Dam, Alexandria and Ruston have patterns significantly related at the 95% level while Monroe and Olla have insignificant relationships with Lake Charles. Nowhere on the map does a more steep gradient between positive and negative relationships appear than between Lettsworth and Baton Rouge.

The correlation field for Lettsworth (Fig. 4-26), also a station with a morning precipitation peak, reveals a similar pattern. In this case all the stations in Louisiana to the north and west of Lettsworth were significantly related at either the 99% or 95% levels. In the southeastern part of Louisiana, no stations east of Opelousas were significantly related. The diurnal pattern

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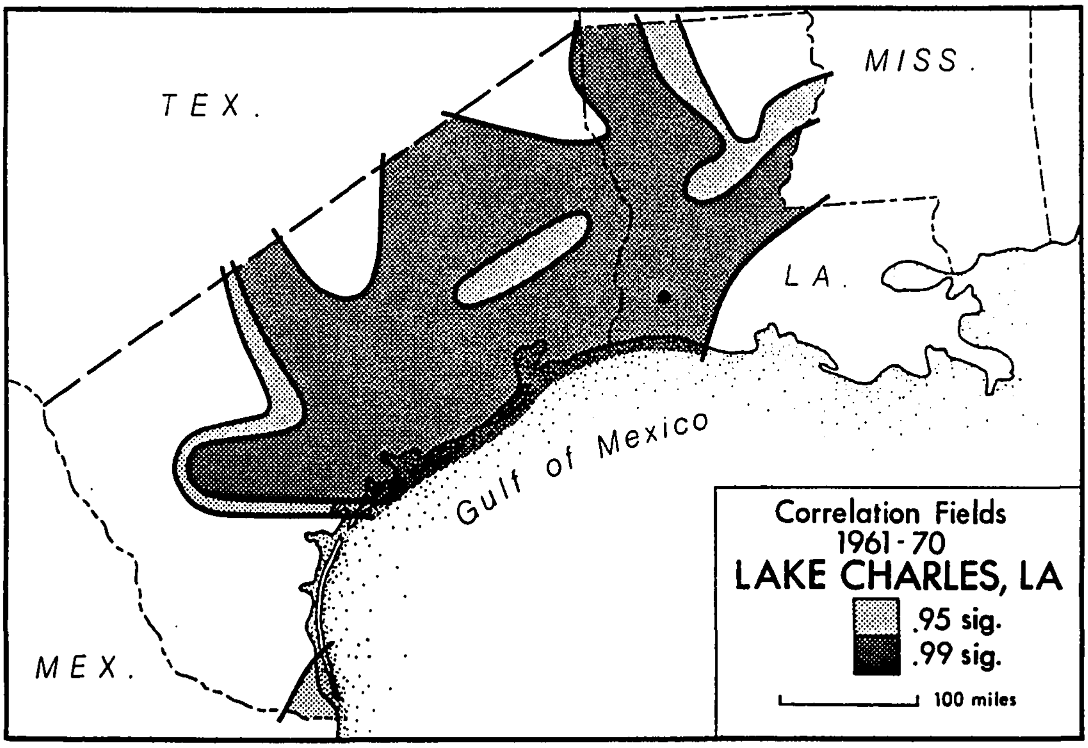

Figure 4-25 Correlation field for Lake Charles, LA, 1961-70.

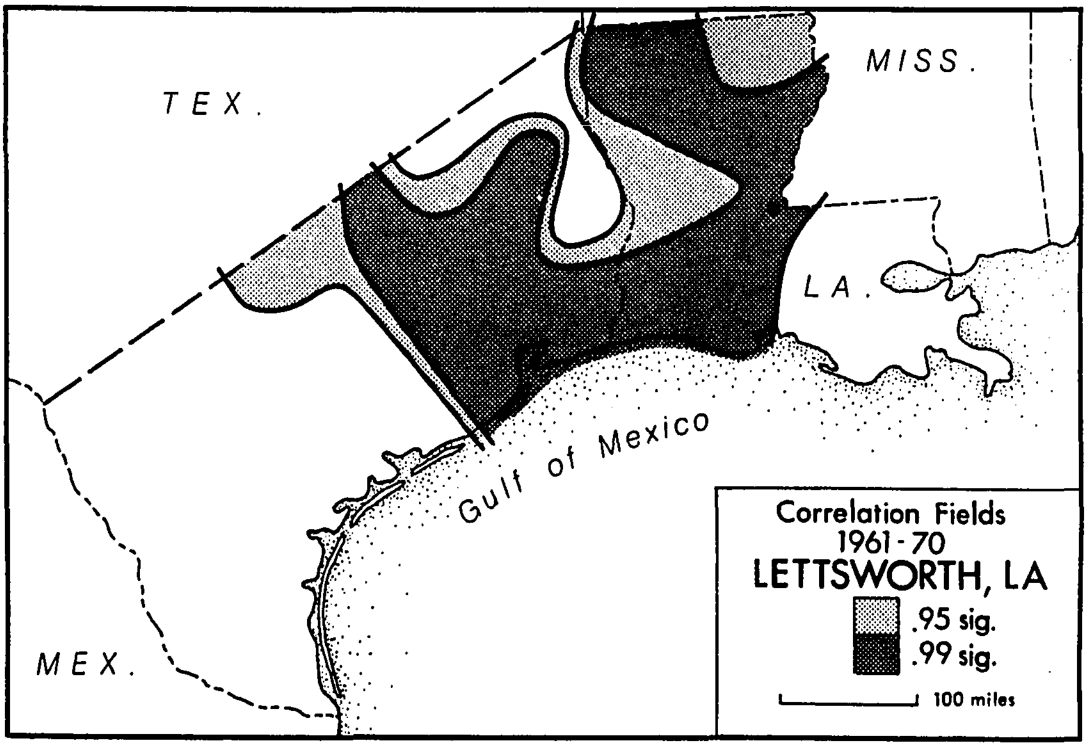

Figure 4-26 Correlation field for Lettsworth, LA, 1961-70.

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at Lettsworth was more closely related to that of Austin, over 400 miles to the west, than it was with that of Baton Rouge.

Monroe (Fig. 4-27), which tended to have a pattern which overlapped both morning and afternoon, had a correlation field which included much of northern Louisiana and some of the southeastern part of the state at the 99% level. A small area north of Houston maintained significance.

At Clinton (Fig. 4-28), an inverse pattern in the correlation field appears when compared to the correlation fields of Lake Charles and other locations with morning peaks. Northeastern and southeastern Louisiana had significant relationships with the Clinton pattern, which had a diurnal peak late in the day, but a southwest to northeast band of insignificance appears. Again, an anomalous relationship appears between Clinton and the area north of Houston.

A series cf 11 correlation fields have been constructed for Louisiana in the 1960's. This was done so that the southwest-northeast band could be analyzed in more detail. The correlation fields for Somerville, Galveston, Houston, Kountze, Port Arthur, Lake Charles and Rockefeller Wildlife Refuge (Figs. 4-29 through 4-35) all reveal this band with significant relationships at the 99% level with both Lettsworth and Vidalia while areas to the north or south are either insignificant or only significant at the 95% level.

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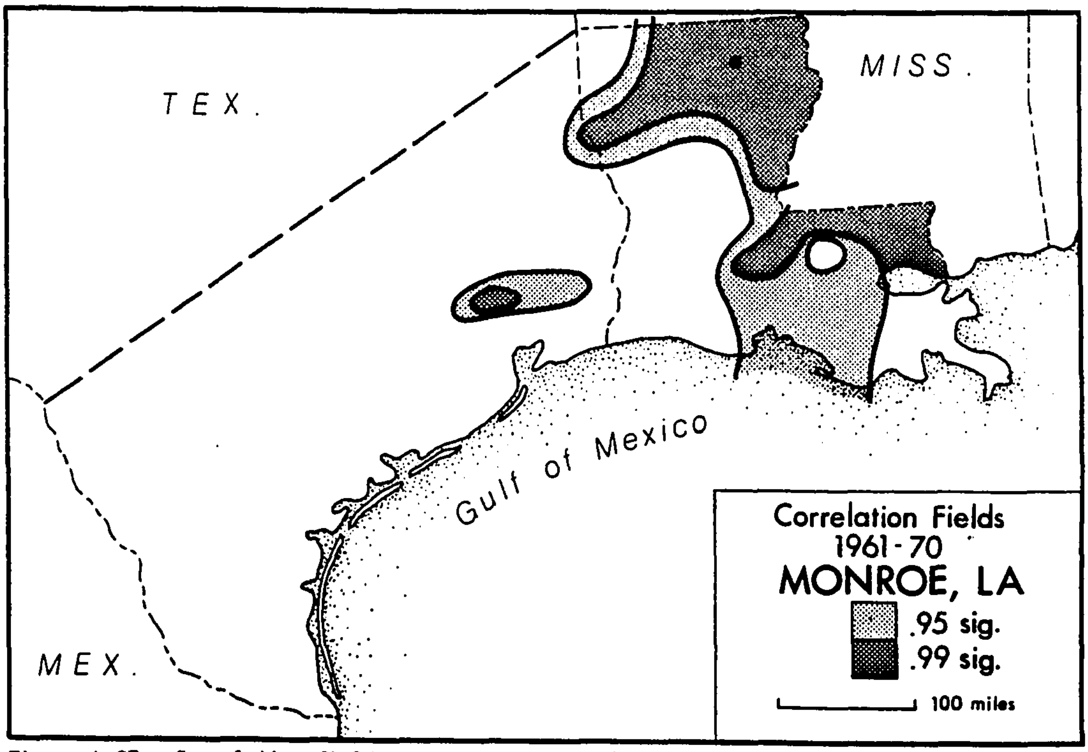

Figure 4-27 Correlation field for Monroe, LA, 1961-70.

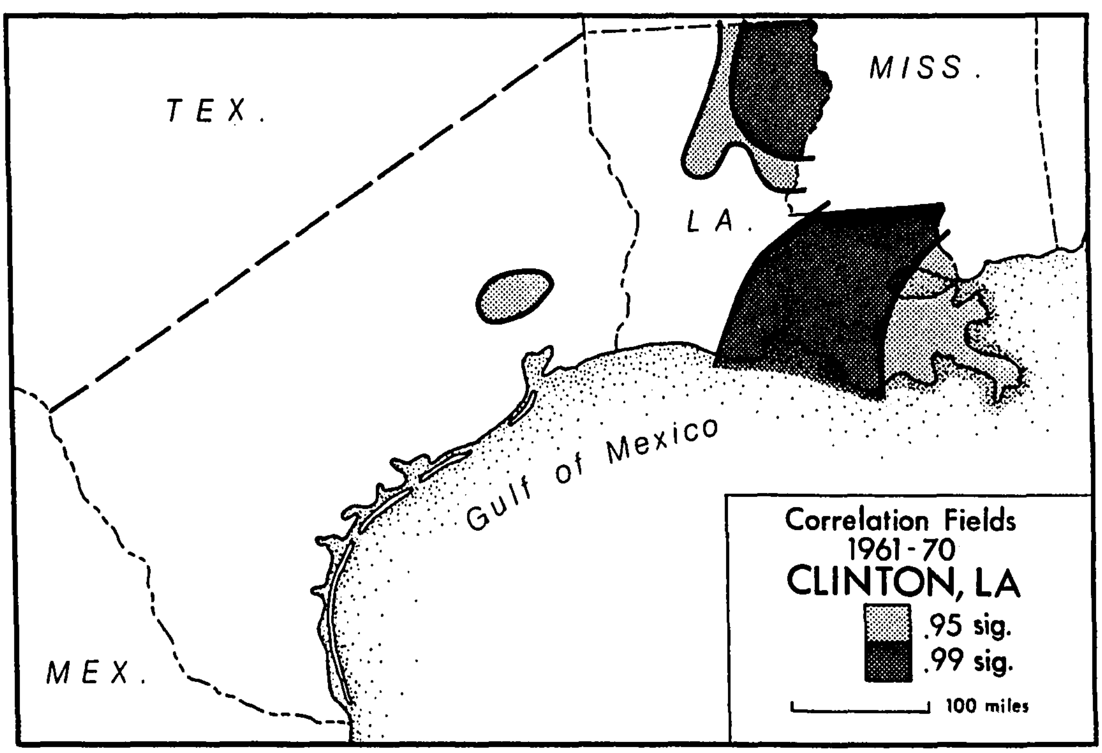

Figure 4-28 Correlation field for Clinton, LA, 1961-70.

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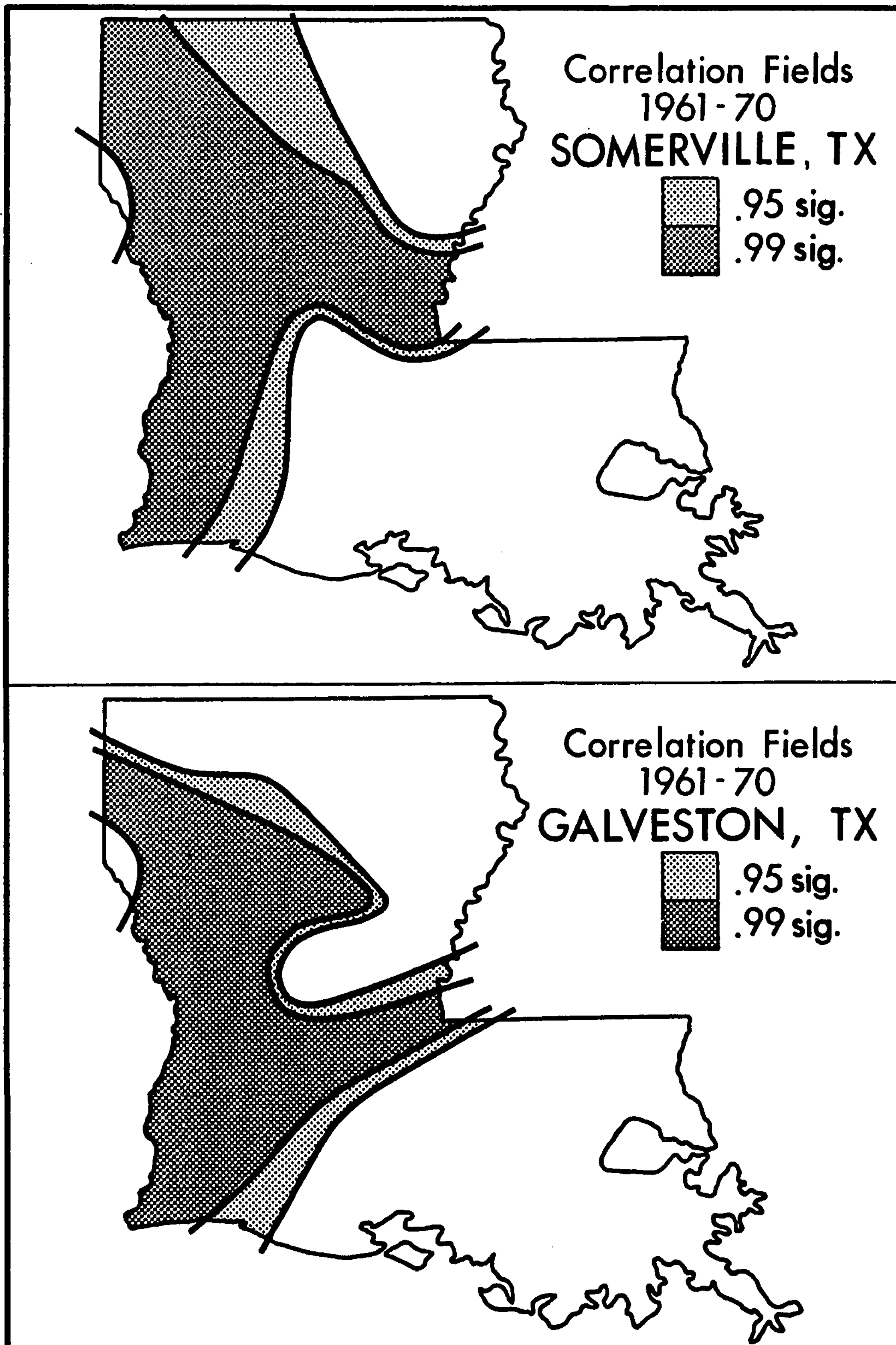

Figures 4-29 and 4-30 Correlation fields for Somerville, TX, 1961-70 and Galveston, TX, 1961-70.

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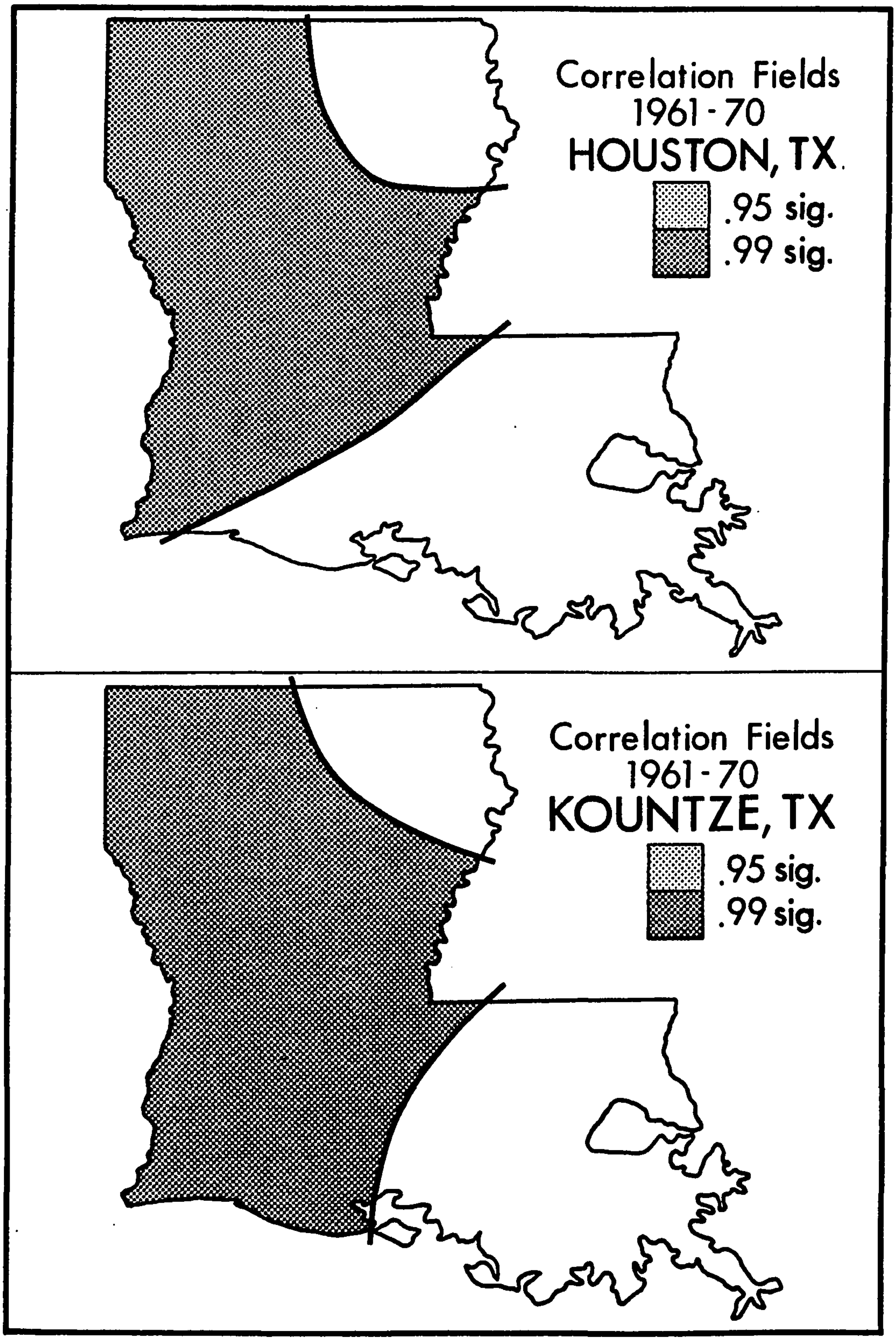

Figures 4-31 and 4-32 Correlation fields for Houston, TX, 1961-70 and Kountze, TX, 1961-70.

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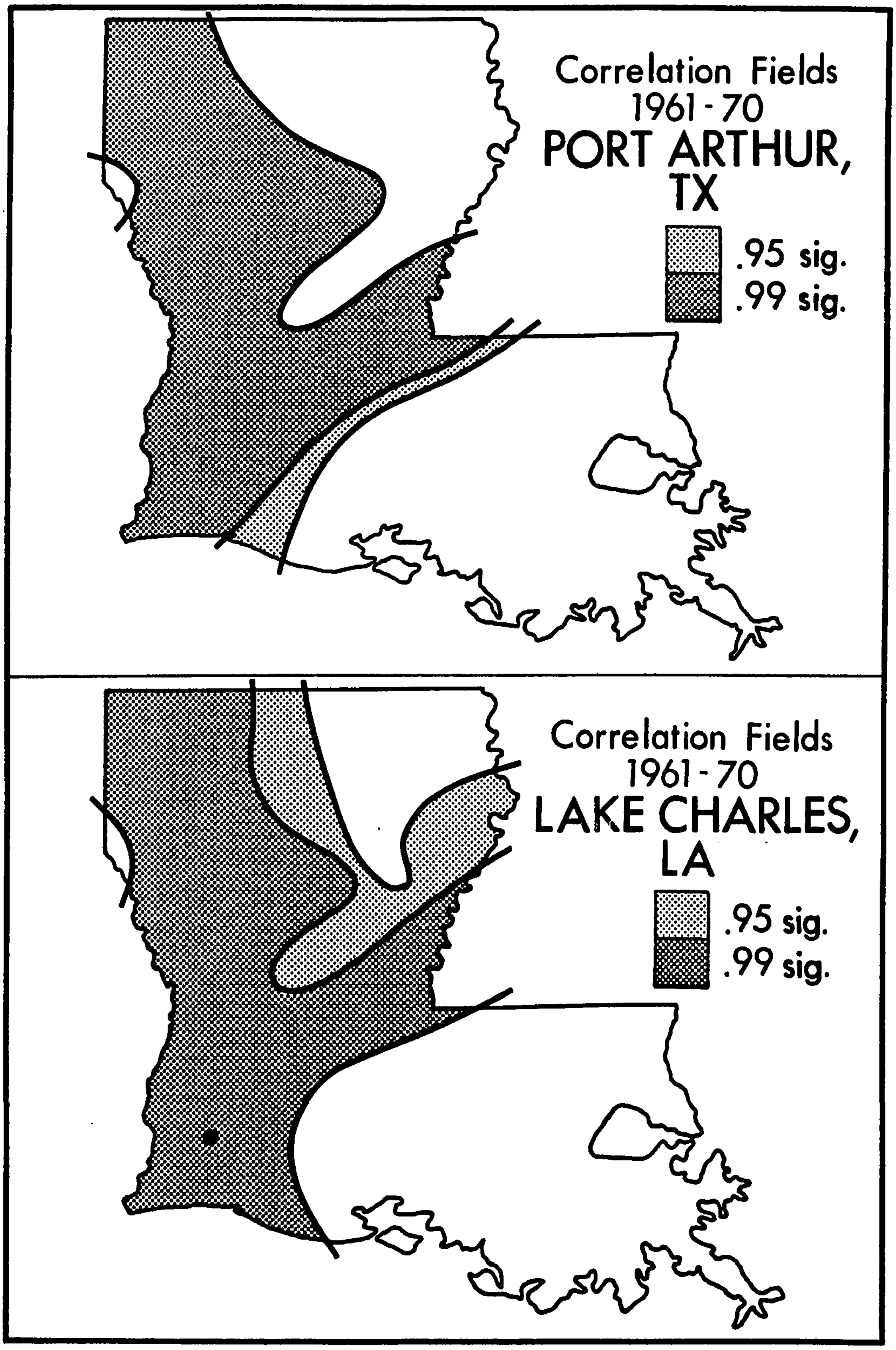

Figures 4-33 and 4-34 Correlation fields for Port Arthur, TX, 1961-70 and Lake Charles, LA, 1961-70.

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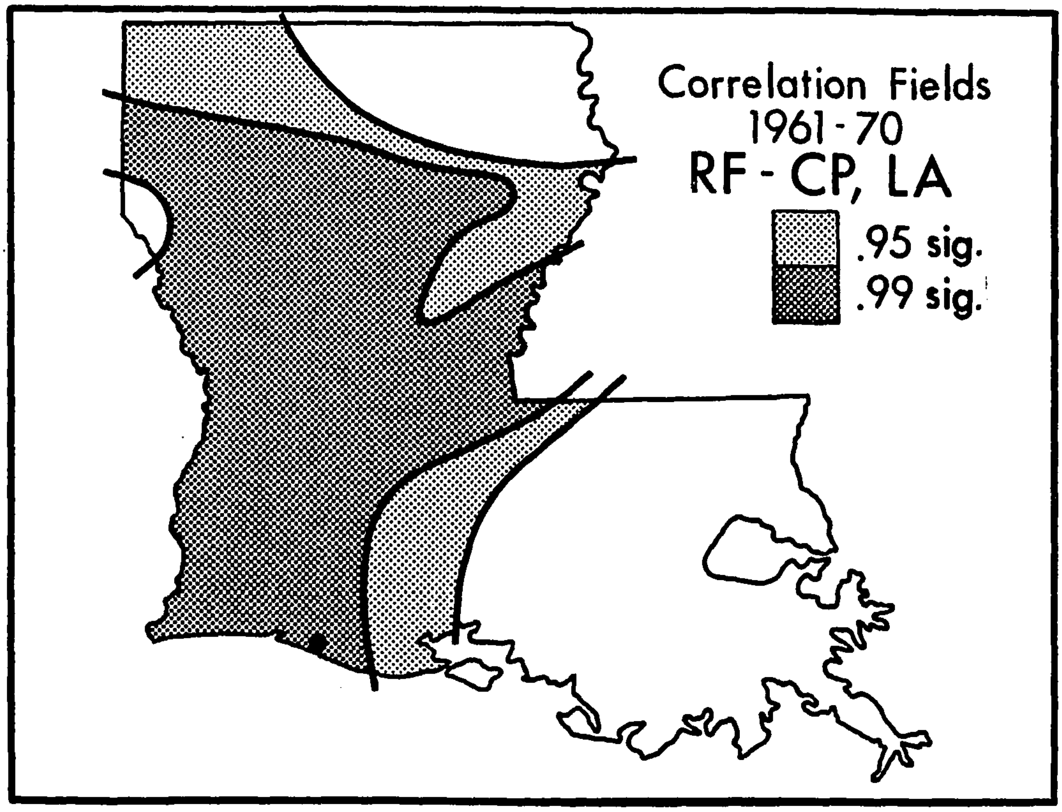

Figure 4-35 Correlation field for Rockefeller Wildlife Refuge-Catfish Point, LA, 1961-70.

The Lettsworth correlation field (Fig. 4-36) again indicates this band with a zone of 95% significance to the north and insignificance to the south and east. The correlation field for Vidalia (Fig. 4-37) indicates that all stations north of a Lettsworth-Opelousas-Rockefeller line had significance levels at the 99% level, but these quickly deteriorated to insignificance at Baton Rouge and French Settlement.

The Morgan City (Fig. 4-38) and Clinton (Fig. 4-39) correlation fields showed insignificant relationships with the western half of Louisiana and as far east as Lettsworth and Vidalia.

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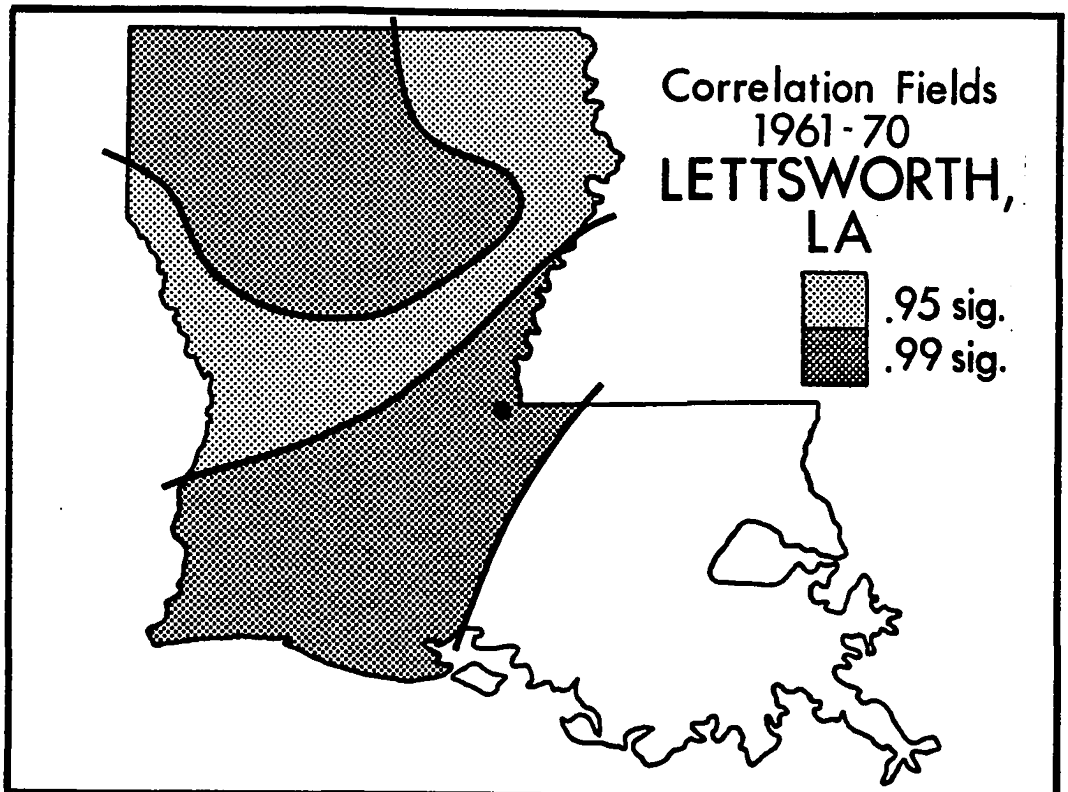

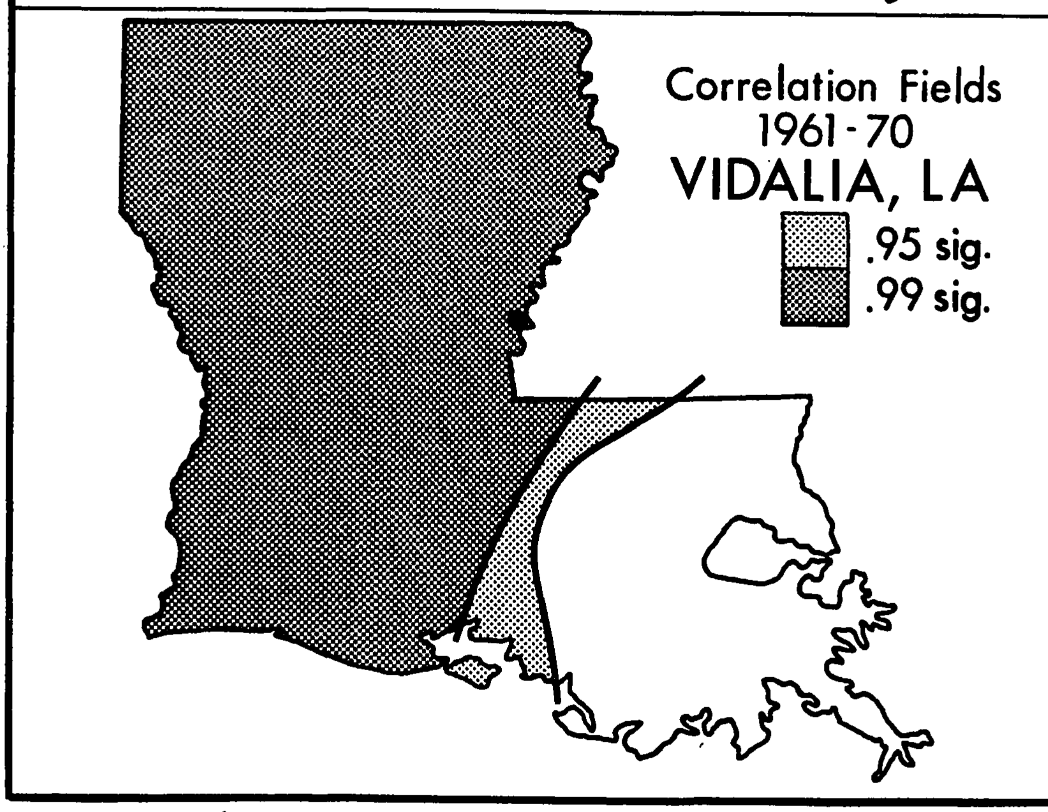

Figures 4-36 and 4-37 Correlation fields for Lettsworth, LA, 1961-70 and Vidalia, LA, 1961-70.

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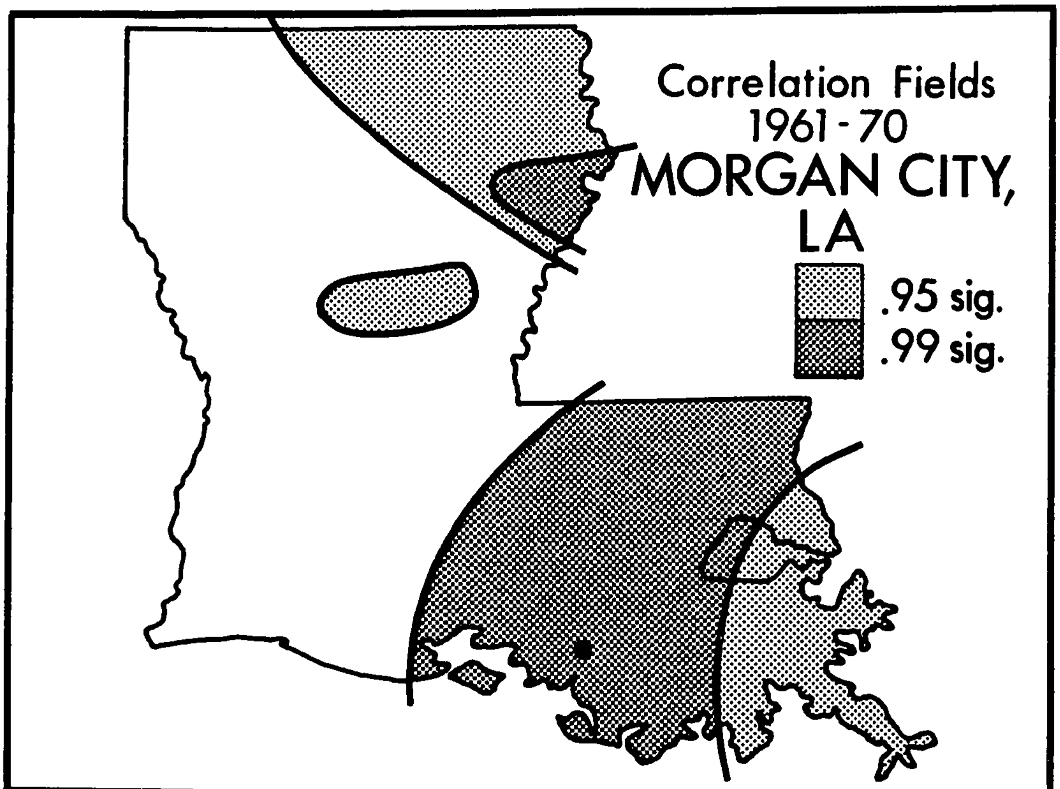

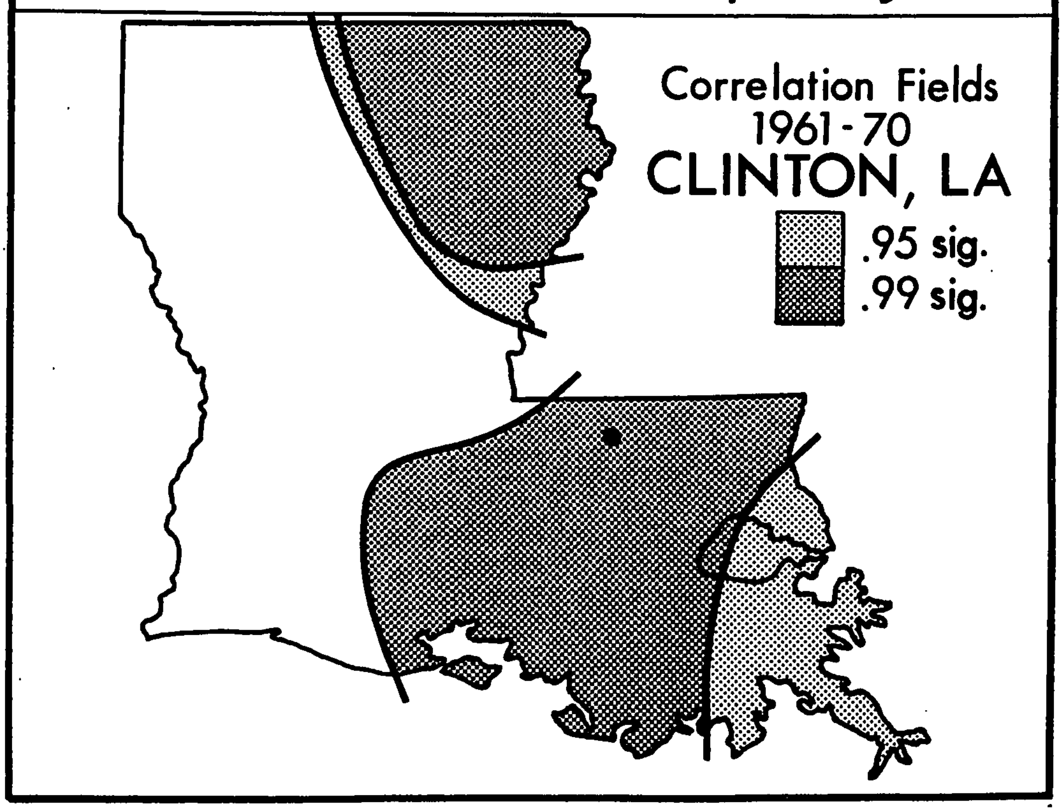

Figures 4-38 and 4-39 Correlation fields for Morgan City, LA, 1961-70 and Clinton, LA, 1961-70.

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Clearly the patterns revealed by the simple mapping of peak hours had some significance. A southwest to northeast band of morning maximums shifted from Texas in the 1950's to Louisiana in the 1960's. Such a pattern has not been observed by previous researchers and such a shifting of diurnal patterns has never been examined. In Chapter Five, the physical factors involved in the creation of of these spatial patterns of diurnal precipitation are discussed.

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CHAPTER V

CAUSAL FACTORS INVOLVED IN THE CREATION AND REDISTRIBUTION OF THE JANUARY DIURNAL PRECIPITATION PATTERNS

As has been established, a distinct southwest to northeast band of morning precipitation existed over Texas in the 1950's and over Texas and Louisiana in the 1960's. Even though the data could not be mapped, the band must have remained in Louisiana during the 1970's. This is because Lake Charles, Galveston, Corpus Christi and Brownsville all maintained their morning peaks while New Orleans and Baton Rouge continued with peaks later in the day over the course of these 10 years. Southern Texas consistently had morning precipitation throughout the study period just as southeastern Louisiana consistently had afternoon and evening peaks through the 30 years. In between these locations, a shift in patterns occurred as stations such as Galveston, Lake Charles, Lettsworth, Leesville and others in that vicinity changed from afternoon to morning maximums. The purpose of this chapter is to explain the processes involved in the creation and shifting of these patterns.

The Morning Peaks in Southern Texas

Throughout all of southern Texas, a distinct morning

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peak was evident in both the 1950's and 1960's. Data for Brownsville and Corpus Christi indicate that this pattern continued into the 1970's. The timing of these rainfall events in this region is related to the mechanism producing much of the rainfall there in January. That mechanism is the Texas-West Gulf cyclone.

As discussed previously, the western Gulf of Mexico is an active zone of cyclogenesis in the winter months. According to Saucier, January is the peak month for the formation of these storms (p. 226). Some of the researchers (Saucier, p. 220, Johnson, et al., pp. 3-4), in discussing the factors involved in the formation of these storms, mentioned that the prime reason for storm development in this location is because of the temperature gradient between the land and the water.

The temperature contrast between the relatively warm waters of the Gulf and the cooler air over the land surface results in an offshore flow. As the air is lifted over the water surface due to the warm surface temperatures, more air is diverted offshore. When a quasi-stationary front is poised along the Texas coast, as is frequently the case during the winter months, wave development is enhanced by this flow. The stationary front also frequently becomes deformed into the shape of the Texas coast (Johnson, et al., pp. 3-4, Atlas, et al.), a shape which lends itself to wave development. If the land-water temperature contrast were not the main reason for the cyclogenesis in this region, then these waves would also form far out over the

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open Gulf, or well inland.

Cyclogenesis, however, is much more likely immediately along the coast according to Bowie and Weightman (p. 1-7). In their study, which covered the period from 1892-1912, they found that 30 of the "Texas type" storms developed during January in the Corpus Christi area, while only 13 developed in the Gulf south of Louisiana and just three over northern Mexico. Of all of the regions delineated by Bowie and Weightman, the southern part of coastal Texas was the most frequent zone of January cyclogenesis over their twenty year study period.

Given that the land-sea temperature gradient is the principle factor in cyclogenesis in this location (when the front is poised over the region), the timing of the development of these systems must be based on the time when this gradient is the steepest. The gradient would be steepest nocturnally, especially in the early morning hours when the land surface reaches its' lowest temperature. Since the sea surface temperatures vary little overnight, the difference between the land and sea temperatures would be greatest between midnight and 8 a.m., when the land temperatures are lowest. This would result in the steepest gradient and strongest offshore flow during those hours. Since all of southern Texas has an early morning rainfall maximum and specialists on Texas weather such as Bomar and Orton claim that these storms are the principle rain producers for that region, the diurnal patterns found in that region must be the result of a diurnal pattern of

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cyclogenesis.

Nocturnal and early morning rainfall is also increased in areas affected by frontal overrunning conditions. This has been examined by both Hewson and Dexter who found that, in the frontal overrunning sector ahead of warm fronts, that rainfall peaked in both intensity and coverage nocturnally. The radiational cooling of the cloud tops and greater potential instability at night were the two reasons that these two researchers found for this diurnal fluctuation. It is also quite likely that since the winds above the planetary boundary layer are stronger nocturnally, this would also enhance the upward motion of the maritime tropical air above the warm frontal or stationary frontal surface. Since southern Texas often experiences frontal overrunning conditions during January when the polar front remains stationary off shore, this could also play a part in the early morning peaks in this region.

The Formation of the Southwest to Northeast Band of Morning Precipitation

This research has shown that a distinct southwest to northeast band of morning precipitation prevailed northeast of the core area of morning precipitation in southern Texas in both the 1950's and 1960's. The band was located in eastern Texas in the 1950's, before it shifted into southern and east-central Louisiana in the 1960's and 1970's. The mean location of this band conforms with the

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principle storm track taken by the Texas-West Gulf cyclones.

In the Florida panhandle, Schwartz and Bosart (1979) concluded that the diurnal precipitation boundary was associated with the mean position of the quasi-stationary polar front over that region (p. 1544). The position of the Florida transition zone conforms well with the mean position of the tracks of storm type Gb, as defined by Elliott (1949, p. 111). The mean position of the transition zone in Louisiana over the thirty year study period (1951-1980) was between Lake Charles and New Orleans which is the track of Elliott's storm type Ga. Both of these storm types are Texas-West Gulf cyclones and the two transition zones are located in the same position relative to the two principle tracks of these storms. There are sound reasons for these transition zones between morning and afternoon precipitation to be associated with these tracks.

The tracks of storms eminating from the western Gulf of Mexico are determined by the winds aloft. According to Bomar, the storms never develop unless the subtropical jet stream is located over the vicinity of the western Gulf (p. 37). When cyclogenesis is taking place over the western Gulf, the subtropical jet stream usually takes on a distinct southwest to northeast orientation, thereby indicating the eventual direction of movement of the system.

Since the winds aloft are much stronger than at the

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surface, impulses of cooler air aloft, generated nocturnally in the zone of cyclogenesis, move rapidly downwind towards the northeast enhancing precipitation along the core of the subtropical jet stream. This accounts for the peaks around 0800 to 1100 hours C.S.T. in the southwest to northeast band downwind from those areas with peaks between 0100 and 0600 C.S.T. The impulses, or waves, would bring light to moderate showers at that time of day along this band. South of this band, in what would be the warm air sector of the storm track, the timing of the rain events would be more closely related to afternoon convective activity.

The movement of the entire system, as it migrates out of the western Gulf of Mexico, may well account for the strong afternoon and evening maxima immediately south of this band. The storm, after generating nocturnally, would move slowly northeast, and the trailing cold front would not reach the New Orleans area until late afternoon. According to Saucier, these storms have an average movement of 620 miles during the first day following cyclogenesis (p. 228). If the low were to develop in the Sarita area between 0100 C.S.T. and 0300 C.S.T., the peak hours for Sarita in the 1960's, then move northeastward at the average velocity of 25 m.p.h., the trailing front would reach the New Orleans area around 5 p.m., which was the peak smoothed hour at New Orleans for that decade. Many of the stations located along the southwest-northeast band do have a second peak in the mid to late afternoon which

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could be associated with the passage of the low pressure area and its' trailing front.

The Shift of the Transition Zone Between Morning and Afternoon Maximums

The thirty-year mean location of the transition zone was beween Lake Charles and New Orleans. However, the position of the zone was in eastern Texas in the 1950's. Since Schwartz and Bosart did not look at trends over time, it is not known whether such a shift occurred in Florida. In fact, researchers of diurnal precipitation patterns in the United States have not closely examined trends over time.

The climate of the eastern and southern United States, during the winter months, differed significantly during the thirty years between 1951 and 1980. January temperatures were warmer and precipitation lower throughout much of the South in the 1950's. Table 5-1 indicates the mean January temperatures and monthly rainfall totals for each of these three decades for selected locations within this study area, as well as within the eastern United States in general.

In each of the 13 locations, the mean January temperature during the 1960's was less than that of the 1950's. In only one case (Tampa), did the mean temperature of the 1970's exceed that of the 1950's. At most locations, the mean January temperature rose somewhat from the 1960's to the 1970's. This rise is largely due

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to the brief warm period in the early to mid 1970's.

Table 5-1

Mean Decadal January Temperatures (F) and Precipitation (inches)

	Boston		Wilmington Del.		Charleston S.C.		Tampa		Pensacola	
Decade	T	P	T	P	T	P	T	P	T	P
1951-60	30	4.4	33	3.0	49	2.9	60	2.3	53	3.5
1961-70	28	3.1	30	2.3	46	3.4	59	2.2	49	4.7
1971-80	30	4.5	31	4.1	49	3.7	61	2.0	53	5.3

	Jackson Miss.		Memphis		BTR		L.C.		N. Orleans	
1951-60	48	4.3	42	6.1	53	3.6	54	3.6	55	4.0
1961-70	44	4.1	38	3.0	49	4.4	50	3.7	50	5.3
1971-80	45	6.6	37	4.8	51	5.7	51	5.5	52	5.6

	C. Christi		Brownsville	
1951-60	59	1.7	63	1.0
1961-70	54	1.4	58	1.7
1971-80	56	1.8	60	1.1

Henry Diaz and Robert Quayle (1978) examined January temperature trends on a regional basis throughout the United States. Louisiana and Texas are located in the "West South Central" region and their data shows decreasing temperature pattern throughout the course of the 1951-80 period. In another publication, Diaz (1980) analyzed mean winter temperature departures from longterm averages over the United States based on the 1895-1979 mean. Table 5-2 displays departures interpreted from the maps in this publication for selected stations in southeastern Texas and Louisiana. These data clearly depicts the downturn in winter temperatures, departures which Diaz (1984) says are largely determined by January temperatures.

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Table 5-3 displays the mean temperatures for each January from 1951-80 at Baton Rouge, Lake Charles, New Orleans, Brownsville, and Corpus Christi. The fluctuation from year to year is evident but so is a dowanward trend of temperatures since 1957.

Table 5-2

Winter Temperature Departures From the 1895-1979 Mean

	Br'vl	Gal'ton	Lake Chas.	Shreve	New O.
1950-51	0.5	0.0	0.0	0.0	-0.5
1951-52	5.0	5.0	5.0	5.0	5.0
1952-53	1.0	1.0	1.0	2.0	1.0
1953-54	1.0	1.5	1.5	2.0	1.0
1954-55	0.0	0.0	0.0	0.0	0.0
1955-56	1.0	1.0	1.0	1.0	1.0
1956-57	4.5	5.0	5.0	4.5	5.5
1957-58	-1.5	-2.0	-2.5	-1.5	-4.0
1958-59	-1.0	-1.0	-1.0	-1.0	-1.0
1959-60	-2.0	-2.0	-2.0	-2.0	-2.0
1960-61	-2.0	-2.0	-2.0	-2.0	-2.0
1961-62	0.5	1.0	1.0	0.5	1.0
1962-63	-3.5	-4.0	-4.5	-4.0	-5.0
1963-64	-5.0	-5.0	-5.0	-4.5	-5.0
1964-65	0.5	0.5	0.5	0.5	0.5
1965-66	-2.0	-2.0	-2.0	-2.0	-2.0
1966-67	-2.0	-2.0	-2.0	-1.5	-2.0
1967-68	-3.0	-3.0	-3.0	-2.5	-3.0
1968-69	0.0	-0.5	-1.0	-1.0	-1.5
1969-70	-2.0	-2.5	-3.0	-2.5	-4.0
1970-71	3.0	2.0	2.0	1.5	1.0
1971-72	2.0	3.0	3.0	3.0	3.0
1972-73	-3.0	-3.0	-3.0	-3.0	-3.0
1973-74	0.5	1.0	1.0	1.0	1.5
1974-75	0.0	0.5	1.0	0.5	1.5
1975-76	0.5	0.5	0.0	1.0	0.5
1976-77	-4.5	-5.0	-5.0	-4.5	-6.0
1977-78	-4.5	-6.0	-7.0	-7.0	-7.0
1978-79	-4.0	-4.0	-4.0	-5.5	-4.0

Source: Diaz and Quayle (1978)

At the beginning of the study period, temperatures at these stations were relatively warm. From 1958 through 1970, temperatures remained below the 30-year mean, for the most part, before a brief warming period from 1971 through

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1975. The coldest months of the period were observed from 1976 through 1979. With the warmest months at the beginning of the study period and the coldest months at the end, an overall downward trend in temperatures is revealed.

Table 5-3

Mean January Temperatures, 1951-80

Year	Br'ville	C. Chris.	L. C.	BTR.	N.Orleans
1951	62	58	53	53	56
1952	67	64	62	61	62
1953	65	61	56	56	57
1954	65	60	55	54	55
1955	63	59	53	51	53
1956	63	59	53	51	52
1957	66	60	57	58	60
1958	58	55	50	48	49
1959	57	53	48	49	50
1960	62	56	50	50	52
1961	56	52	47	44	47
1962	56	51	48	48	51
1963	56	50	46	47	48
1964	60	57	49	50	50
1965	63	59	55	53	55
1966	54	51	48	45	47
1967	59	56	53	52	53
1968	58	53	51	50	52
1969	64	59	54	53	54
1970	58	51	46	46	47
1971	67	62	56	53	55
1972	66	62	56	57	59
1973	55	55	49	49	50
1974	61	58	58	61	63
1975	62	60	57	56	57
1976	59	57	50	49	51
1977	55	50	43	43	42
1978	55	49	43	43	44
1979	56	51	44	43	46
1980	64	60	54	53	56

Source: N.O.A.A. Climatological Data

Climatologists have long known that there are regional and local relationships between temperature and rainfall patterns. The upper air patterns responsible for the colder temperatures of the 1960's and 1970's must have had

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an effect on the precipitation intensity, duration, and timing. In the study area under investigation in this research, there appears to be a trend towards greater precipitation in colder Januaries. In the case of Baton Rouge, Lake Charles, New Orleans and Brownsville, the 1950's, the warmest of the decades, was also the driest. Only Corpus Christi had a higher mean precipitation in the 1950's and this is, in large part, due to the 10.8 inches of rain which fell in the "cool" January of 1958.

In order to understand the relationship between cold temperatures and the frequency of hourly rainfall events, simple correlations were made between the average monthly decadal temperature and both the total monthly decadal rainfall totals as well as the monthly decadal frequency of hourly rainfall events. This was performed because most of the stations in the study area not only had an increase in total rainfall, but also had a marked increase in the total hours of rain over the course of the 1960's than they had in the 1950's. Table 5-4 indicates the frequency of hourly rainfall events at five of the first-order locations in the study area.

The correlations run between the temperature and total precipitation revealed a relationship of R= -.83, indicating that as temperatures went down, the amount of rainfall increased. For the relationship between temperature and the number of hourly events, as shown in Table 5-4, the relationship was even stronger at R= -.86. Therefore, as temperatures declined, more hours of rain were measured

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along this transect.

Table 5-4

Monthly Decadal Frequency of Hourly Rainfall Events at Selected Locations in Southeastern Texas and Louisiana

	1950's		1960's		1970's	
Location	#hours	temp	#hours	temp	#hours	temp
B'ville	230	63	388	58	296	60
C. Christi	243	58	366	54	448	56
L. Charles	372	54	509	50	618	51
B. Rouge	379	53	558	49	618	50
N. Orleans	379	55	601	50	574	53

Similar relationships between temperature and precipitation have been observed elsewhere in the Gulf coastal region. James Coleman (1982), in a study of seasonal rainfall and temperature relationships in peninsular Florida, found that "winter rainfall decreased approaching the temperature maximum of the 1940's and increased thereafter" (p. 145). The relationship between precipitation and temperature in the winter was "highly significant."

January temperatures in Louisiana and southeastern Texas declined after 1957 and there is a significant relationship between cold temperatures and greater total precipitation as well as with total hours of precipitation. Such a relationship is not surprising, because in colder years, the polar jet stream, the polar front, and storm tracks are all displaced farther south over the Gulf of Mexico. The climate is much stormier under these conditions than when the front and storm tracks are to the north in warmer Januaries. The colder Januaries of the

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1960's and 1970's resulted in more hours of rainfall within this study area than did the warm 1950's.

Since the southwest to northeast band of morning rainfall is associated with the mean location of the polar front and its' associated storm tracks, the mean postition of this band would be farther to the north in the warmer 1950's than it was in the 1960's and '70's. This is indeed the case and this explains the south and eastward shift in the location of this band in the last two decades of this study period. The rainfall data for Memphis (Table 5-1) in the 1950's shows that Januaries were wetter then than in the next 20 years. This is because during the 1950's, the storm tracks were displaced to the north, leaving Memphis under the dominant track over the course of this decade.

An example of the typical tracks of storms in the 1950's appears in a publication by L.P. Stark and D.A. Reiter entitled "Cyclogenesis in the Gulf States, January 1954" (1954). Stark and Reiter examined three storms, two of which developed in eastern Texas and moved northeastward over Shreveport and towards Memphis. The third storm took the more usual track taken by storms in the 1960's and '70's. In the case of the third storm, temperatures behind the front were colder than in the first two cases and the front extended farther south into the Gulf of Mexico, unlike the first two fronts.

Colder winters mean that the polar front is found more often over the Gulf of Mexico, therefore giving birth to

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more Texas-West Gulf cyclones and more rainfall in southeastern Texas and Louisiana.

Upper air data can also be used to indicate changes in general circulation patterns. For this purpose, maps and data have been studied from the N.O.A.A. publication National Weather Summary which contains monthly summaries of upper air wind patterns over the United States as well as local information. Of the stations in the study area, only Brownsville, Texas had a good period of record from 1951 through 1970. From this information, changes in upper air wind direction, wind speed and temperature may be extracted at various levels of the atmosphere. Table 5-5 indicates the 500 mb average wind direction and speed as well as mean temperature for each January from 1951 through 1970 at Brownsville, Texas.

On average, the wind speed at the 500 mb level at Brownsville was 26.5 knots in the 1950's and it increased to 33.0 knots in the 1960's. The increase in wind velocity at the 500 mb level was also accompanied by a slight shift towards more southwesterly winds. The mean wind direction at the 500 mb level in the 1950's was 261 degrees, or just south of due west. In the 1960's, the mean direction was 258 degrees, indicating a slightly more southwesterly flow. A similar shift from westerly to more southwesterly was also evident at the 700 mb level as winds shifted from 252 degrees to 242 degrees in the 1960's. The increased velocity of the winds at the 500 mb level was the result of increased frontal activity in

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Table 5-5

Average January 500 mb conditions at Brownsville, TX, 1951-70

YEAR	DIR.	SPEED (KNOTS)
1951	W.	30
1952	S.W.	25
1953	W.	30
1954	W.S.W.	25
1955	W.S.W	35
1956	W.	20
1957	S.W.	20
1958	W.S.W.	25
1959	W.	25
1960	W.	30
1961	W.S.W.	35
1962	W.	35
1963	W.	40
1964	W.	50
1965	W.	20
1966	W.S.W.	40
1967	S.W.	25
1968	W.S.W.	25
1969	W.	25
1970	W.	35

southern Texas and the adjacent coastal waters. The shift towards a more southwesterly flow aloft is an indication of the increased entrenchment of the subtropical jetstream which feeds into the western Gulf of Mexico at the mid and upper levels of the atmosphere. Due to the southward displacement of the polar front and the increased cyclogenesis in the western Gulf of Mexico, the subtropical jet stream was increasingly located over the region in the 1960's and 1970's. The greater southwesterly flow aloft in the 1960's would cause precipitation areas which form over the western Gulf of Mexico to spread more northeastward towards Lake Charles than if there had been a westerly flow aloft.

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The height of the 700 and 500 mb levels also give an indication of the changes in atmospheric pressure over the Brownsville area (Table 5-6).

Table 5-6

Average monthly height of the 500 and 700 mb level, 1951-70

YEAR	500 mb HEIGHT (METERS)	700 mb HEIGHT (METERS)
1951	5798	3138
1952	5871	3174
1953	5806	3144
1954	5838	3164
1955	5796	3136
1956	5798	3140
1957	5849	3173
1958	5730	3091
1959	5787	3127
1960	5801	3137
1961	5785	3134
1962	5787	3129
1963	5783	3124
1964	5768	3117
1965	5778	3128
1966	5736	3097
1967	5778	3124
1968	5791	3138
1969	5772	3113
1970	5750	3109

Since lower heights of these levels indicates lower pressure at these levels, it may be assumed that the lower heights of the 1960's may be attributed to the greater persistence of the polar front in the region as well as the increased cyclogenesis. The two years with the lowest heights were 1958 and 1966, both El Nino years and Januaries with excessive hourly precipitation events at Brownsville. The average height of the 700 mb level fell from 3142.4 meters in the 1950's to 3121.3 meters in the

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1960's. A similar fall, from 5807.4 meters to 5772.8 meters was observed at the 500 mb level.

Upper air data at Brownsville supports the hypothesis that the polar front and cyclogenesis were more prevalent in the western Gulf of Mexico in the 1960's and that precipitation forming in the Gulf would move more northeastward in the 1960's.

The Relationship Between the Louisiana and Florida Transition Zones

Schwartz and Bosart found that the transition zone between morning and afternoon precipitation in Florida was most pronounced in the late winter (February). My previous research showed that the morning precipitation maximum in Lake Charles and western Louisiana disappears in February but is prominent in December. Therefore, it appears that the track for storms moving out of the western Gulf of Mexico moves towards the Florida panhandle instead of towards Louisiana later in the winter. Also, there appears to be an eastward migration in cyclonic activity in the Gulf towards Florida (Bowie and Weightman, p. 1-16). Such an eastward shift in storm tracks occurs because circulation patterns change in the late winter.

According to Elliott (p. 110), in late winter and spring, a shift in the "region of cold air-mass genesis to the north" occurs. "It would appear," says Elliott, "that the cold pole of the Northern Hemisphere shifts eastward, which indeed it does, starting out in northeastern Siberia

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in winter and shifting over to Greenland by summer."

Bryson and Hare (1974) discussed the same pattern, explaining that by March the Alaskan ridge and the eastern trough both drift eastward (p. 27). Such an eastward drift of the core area of cold air-mass outbreaks would result in an eastward drift of storm tracks coming out of the Gulf. This would account for the late winter formation of the Florida transition zone and the disappearance of the Louisiana transition zone in February. Elliott alluded to the greater likelihood of Texas-West Gulf cyclones taking the Florida track in late winter (p. 113).

It has now been established that the January diurnal precipitation patterns in southeastern Texas and Louisiana are closely tied to the diurnal nature of cyclogenesis in the Gulf of Mexico. In order to further analyze the processes involved, the following chapter is devoted to the detailed examination of the thirty year diurnal rainfall patterns at Lake Charles, a location which shifted from afternoon maximums to morning maximums.

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CHAPTER VI

JANUARY DIURNAL PRECIPITATION AT LAKE CHARLES: A DETAILED ANALYSIS AND WEATHER TYPE IMPLICATIONS

The purpose of this chapter is to examine the diurnal patterns of hourly precipitation at Lake Charles in great detail and to determine the synoptic weather type(s) underlying the basic nature of the diurnal distribution of hourly rainfall events. Lake Charles was chosen for this analysis for two major reasons. The first is because Lake Charles is a first-order station which keeps hourly wind data, relative humidity, and other weather data which is helpful in determining synoptic weather types. The second reason that Lake Charles was chosen is that Lake Charles was one of the few first-order stations to undergo a shift in the diurnal pattern of hourly precipitation events. Such a detailed analysis gives an insight into the processes involved in the creation and shifting of these diurnal patterns. The synoptic weather type approach utilized in this research was developed by R.A. Muller (1977).

Each hourly precipitation event during the Januaries from 1951 to 1980 was recorded by amount, time of day and associated wind direction. The daily weather maps and Local Climatological Data were then employed to determine the synoptic weather type associated with each hourly

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precipitation event. Of the eight weather types delineated in this synoptic weather type system (Fig. 6-1), four were found to produce rainfall events. These four were Coastal Return (CR), Frontal Gulf Return (FGR), Frontal Overunning (FOR), and Gulf Return (GR).

Analysis of the 1951-1980 Data

Of the 1496 hourly precipitation events over the 30-year period, Coastal Return was responsible for 16 events (approximately 1% of all events). Coastal Return weather is characterized by easterly winds, increasing humidity and generally partly cloudy weather. The small percentage of rainfall events associated with this type is not surprising in the winter. In the summer months, there are more events with this type due to afternoon convection. The average hourly intensity of a Coastal Return event was .06", the lightest of the four types.

Frontal Gulf Return weather was responsible for 362 events over this period (24%). During Frontal Gulf Return weather, winds are generally southerly or southwesterly, precipitation is showery and skies are partly to mostly cloudy. The forced lifting along the frontal boundary leads to occasional heavy events and this is evident in the average hourly intensity of precipitation during FGR weather (.12) which is the highest of the four types.

Frontal Overunning weather made the greatest contribution to the total hours of rainfall with 1063 events (71%). Frontal Overunning weather is characterized

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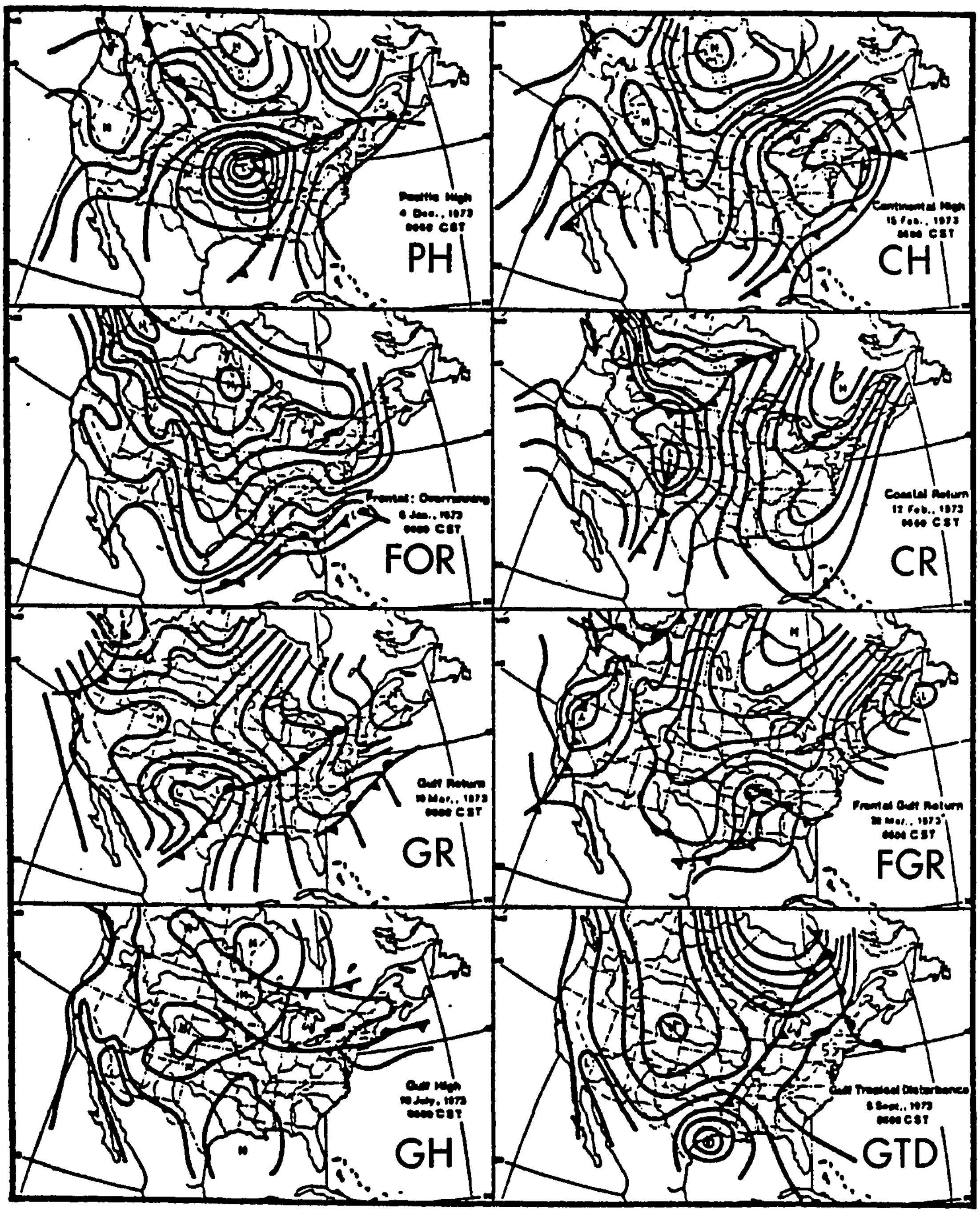

Figure 6-1 Synoptic weather types for Louisiana (after Muller, 1977)

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by overcast skies, northerly or northeasterly winds, light rain or drizzle and cool to cold temperatures. Since the lifting which takes place during FOR weather is generally not as great as that of FGR, the intensity of precipitation is less, but is surprisingly high at .07", with one event recorded with 1.27". The relatively high value for intensity during FOR events is probably associated with waves which pass over or near the Lake Charles area. As has been noted by Schwartz and Bosart (p. 1544), areas just to the north of the quasi-stationary polar front may receive excessive amounts of rainfall as waves migrate northeastward.

Gulf Return weather, responsible for 55 events (4%), generally has southerly winds, high humidity, partly cloudy skies and only scattered showers, fewer in the winter. The average intensity of a GR event was .10".

Table 6-1 displays the 30-year statistics associated with each weather type.

Table 6-1

Statistics associated with precipitation by synoptic weather type, 1951-80

TYPE	N	INTENSITY	ST. DEV.	MIN	MAX
CR	16	.06	.084	.01	.32
FGR	362	.12	.183	.01	1.33
FOR	1063	.07	.118	.01	1.27
GR	55	.10	.166	.01	.97

The two dominant rainfall producing weather types, FGR and FOR, were together responsible for 95% of all events.

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Such a conclusion is not out of order for mid-winter since the other types are much more reliant upon convectional forces to initiate rainfall, forces which are not strong in January.

Table 6-2 indicates the diurnal distribution of hourly rainfall events and associated weather types for the entire study period. It can be readily observed that the fluctuation in the frequency of hourly events closely follows that of the frequncy of FOR events. Since FOR weather is responsible for 71% of all events, such a conclusion is not unexpected. In fact, the relationship between the diurnal distribution of FOR events and the total distribution of events is .94 (Pearson Product Moment) while the relationships between FGR and the total is .50 (significant at the 95% level), between GR and the total is .40 (insignificant) and between CR and the total is -.12. Therefore, there is a very strong relationship between the diurnal distribution of rainfall events associated with FOR weather and the total distribution of rainfall events, while that relationship weakens somewhat between FGR and the total distribution.

Figure 6-2 has been constructed so that the diurnal variability of the total frequency, FGR frequency and FOR frequency may be observed. It is apparent that both the FGR and FOR distribution peaked around 0900 C.S.T. This suggests that there is indeed a diurnal pattern to the passage of waves in the Lake Charles area as has been anticipated in the previous chapters.

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Table 6-2

Diurnal frequencies of hourly precipitation events by weather types, 1951-80.

TIME	N	CR	FGR	FOR	GR
0100	53	0	15	38	0
0200	44	1	11	31	1
0300	49	1	9	38	1
0400	50	1	16	32	1
0500	53	0	17	35	1
0600	60	0	16	41	3
0700	70	0	14	54	2
0800	76	0	17	58	1
0900	86	0	21	61	4
1000	80	0	19	59	2
1100	69	1	8	58	2
1200	72	2	17	51	2
1300	65	0	17	47	1
1400	64	0	15	47	2
1500	68	2	15	45	6
1600	63	2	13	42	6
1700	64	1	16	43	4
1800	71	1	17	48	5
1900	53	1	10	40	2
2000	56	0	14	38	4
2100	59	0	18	40	1
2200	56	1	18	36	1
2300	56	1	16	38	1
2400	59	1	13	43	2

Analysis of the 1950's Data

In the 1950's, as discussed previously, Lake Charles had an afternoon maximum in the frequency of hourly precipitation events. Figure 6-3 indicates the diurnal curve of hourly precipitation distribution for this decade. Of the three decades, the 1950's had the fewest hourly rainfall events with 374. This is much less than the 1960's total of 506 and the 615 of the 1980's. This has been hypothesized to be because of the northward displacement of the polar front and its' associated storm tracks in the 1950's.

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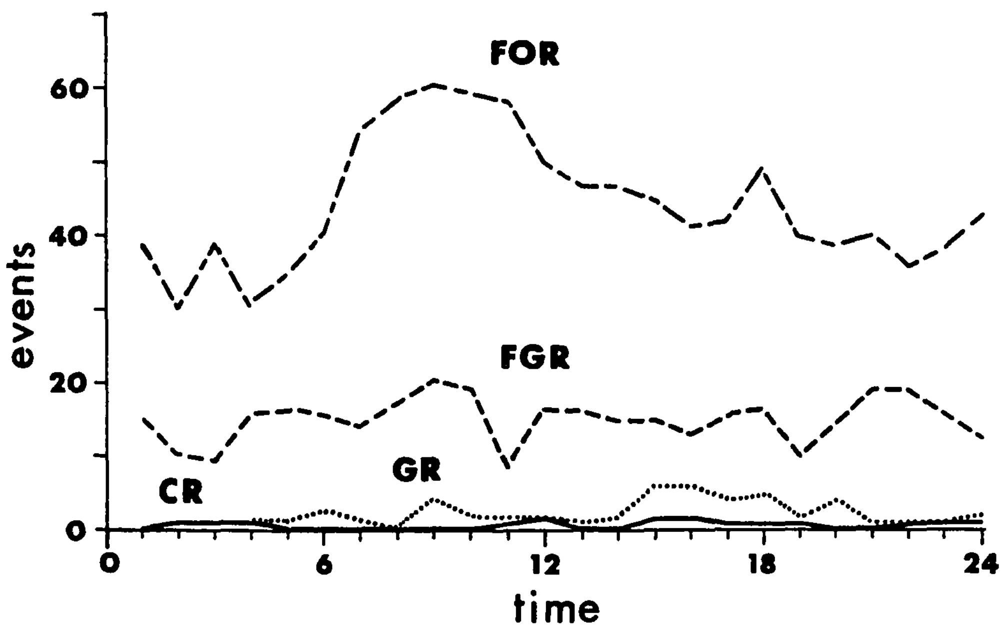

Figure 6-2 January diurnal frequency of hourly precipitation events (1951-80) by synoptic weather types at Lake Charles, LA.

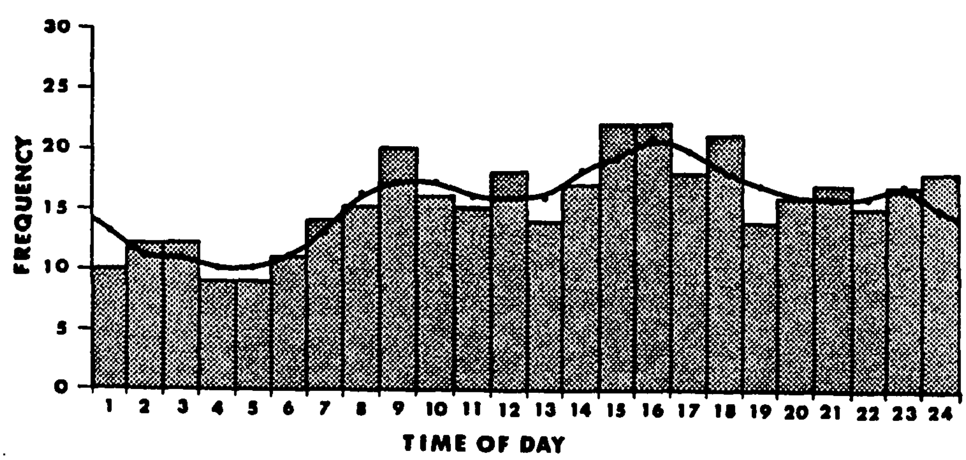

Figure 6-3 January diurnal precipitation frequencies for Lake Charles, LA, 1951-60.

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During the 1950's, the percentage of hourly rainfall events occurring in FGR conditions was above the 30-year mean at 25%. FOR conditions accounted for 64% of all events, well below the mean of 71%. Both GR and CR had their greatest decadal percentages of total events with 2% and 8% respectively. These values are within the expected range because during the 1950's, there would have been fewer storms in the Gulf of Mexico and the polar front would have penetrated into the Gulf less frequently. This would result in a relatively low value for FOR conditions and a relatively higher value for the other three types. Over 57% of all GR events and 50% of all CR events from 1951 through 1980 were observed in the 1950's. Table 6-3 displays the statistics associated with the four precipitation producing weather types for 1951-60.

Table 6-3

Statistics associated with the precipitation producing weather types: 1951-60

TYPE	N	INTENSITY	ST. DEV.	MIN	MAX
CR	8	.03	.049	.01	.15
FGR	94	.10	.141	.01	.83
FOR	241	.10	.140	.01	1.22
GR	31	.08	.130	.01	.53

Over the 1950's, the average intensity of a FGR event and a FOR event were approximately equal. Of the three decades, the average intensity of .10" for the FOR was the greatest, as the intensity dropped to .06" in the 1960's and .07" in the 1970's. In all likelihood, the higher intensity in the 1950's was because a greater percentage of

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the FOR events in the 1950's were associated with frontal passages, rather than lows passing to the south of Lake Charles. FOR rainfall events associated with frontal passages would be heavier than would the more general, steady rains that fall when the polar front and storm tracks are to the south. The rainfall intensities of the vast majority of the hours when the polar front is offshore are quite light, and the occasional heavy FOR events that occur as the West-Gulf Texas cyclones migrate northeastward are diluted by the vast number of low intensity hours.

The distribution of diurnal events and their mean properties can be observed in Table 6-4. The distribution is bi-modal in character, with the peak hour occurring at 1500. The hourly intensities are quite irregular with the greatest single hour intensity of .18" occurring at 0600 and the greatest 3-hour intensities observed between 1700 and 1900. The two heaviest events occurred in the early morning hours with the maximum of 1.22" falling at 0400 and 1.02" falling at 0600. The early morning maximum events along the Gulf Coast agree with the findings of Wallace (1975) and Crysler et. al. (1982) who found that excessive events are more likely nocturnally.

Figure 6-4 shows the diurnal variation of precipitation events associated with these four types during the 1950's. The bi-modal patterns are evident with both FGR and FOR having peaks in the mid morning and late afternoon. The late afternoon peaks appear to be combinations of a major peak in FOR as well as the major

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Table 6-4

Statistics associated with the diurnal precipitation distribution: 1951-60

TIME	N	INT.	ST.DEV.	MIN	MAX
0100	10	.08	.080	.01	.22
0200	12	.10	.091	.02	.34
0300	13	.10	.123	.01	.34
0400	9	.16	.399	.01	1.22
0500	9	.09	.126	.01	.41
0600	11	.18	.304	.01	1.02
0700	14	.09	.131	.01	.45
0800	14	.07	.069	.01	.25
0900	21	.08	.125	.01	.47
1000	16	.05	.065	.01	.23
1100	15	.04	.035	.01	.12
1200	18	.10	.113	.01	.47
1300	15	.10	.125	.01	.45
1400	17	.09	.080	.01	.26
1500	22	.05	.050	.01	.18
1600	21	.09	.118	.01	.46
1700	18	.16	.189	.01	.62
1800	21	.14	.149	.01	.61
1900	14	.13	.136	.01	.45
2000	17	.11	.194	.01	.83
2100	17	.08	.060	.01	.25
2200	14	.07	.088	.01	.31
2300	17	.12	.108	.01	.31
2400	18	.08	.120	.02	.53

peak for GR. The number of FGR events drops off from 1600 through 1900 while FOR reaches its numerical peak of 15 events at 1800. FOR once again had the best relationship with the overall distribution, but this relationship was lower than the 30-year relationship (.78 as opposed to .94 for 1951-80). FGR and CR were insignificantly related to the overall pattern at the 90% level but GR was significant at the 95% level (.59).

The peak of GR in the late afternoon, combined with the FOR peak at the same time, played the greatest role in the creation of the overall pattern. However, the

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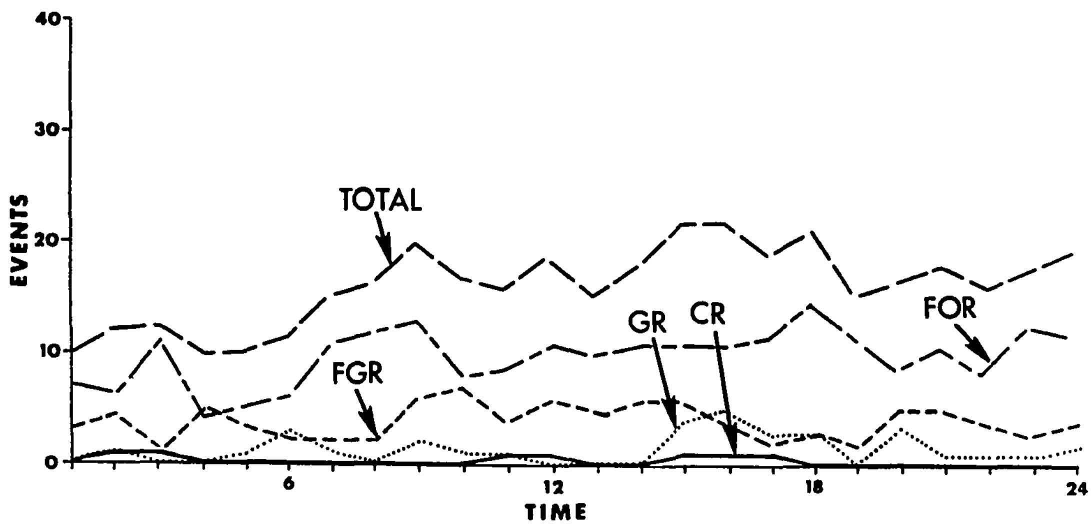

Figure 6-4 January diurnal frequency of hourly precipitation events (1951-60) by synoptic weather types at Lake Charles, LA.

processes involved in the creation of precipitation events in these two types are different. The GR peak in the afternoon is probably related to afternoon convection in these relatively warm Januaries while the FOR peak must be related to the timing of the passage of cyclonic systems. Since FGR values remain relatively high from 0900 to 1500 followed by an increase in FOR, it could be assumed that the late afternoon was a time for frontal passage as the lows which originated in south and western Texas in the morning hours migrated northeastward through the day. The trailing cold front would pass through the Lake Charles area late in the day, preceded by FGR weather and followed by FOR weather. From 1700 through 0300, there were only 36 FGR events as opposed to 117 FOR events. Prior to the

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assumed "mean frontal passage" or "mean wave passage" at 1600, there were 44 FGR events in the 0900 through 1600 time period as opposed to 73 FOR events. This means that FGR events were more likely from mid morning through mid-afternoon, but much less likely after that time.

If the greater frequencies of GR and CR events, as well as fewer overall events are related to the weather conditions resulting from a northward displacement of the polar front, then the frequencies of CR and GR events should be greater and the overall frequency lower in the 1951-55 period than in the 1956-60 period. The average temperature in the first five years of the decade was 55.6, a value wich fell to 51.5 in the last five years. The warmer temperatures from 1951-55 resulted from the less frequent penetration of the polar front to the Gulf of Mexico.

The frequencies of GR and CR events were greater in the first five years as 5 of the 8 CR events and 20 of the 31 GR events occurred in the 1951-55 period. Overall frequencies were lower in the first five years; from 1951-55, 186 events were recorded while from 1956-60, there were 232 events, a 25% increase over the first five years. Since the Januaries between 1956-60 were cooler, it can be assumed that the polar front penetrated the Gulf more often, resulting in an increase in storminess and more hours of rain.

The frequencies of both FGR and FOR rose in the latter five years, with FGR rising from 44 to 61 and FOR from 117

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to 157. The intensities dropped overall from .11" to .09". The drop can be primarily attributed to the drop in FGR intensity from .14" to the 1956-60 average of.06". GR intensities dropped slightly (.09" to .07") but FOR intensities increased from the .10" of the 1951-55 period to .11".

In the warmer earlier five years, the afternoon peak was more dominant while in the latter five years, mid-morning rainfall increased (see Fig. 6-5). The peak hour in the 1951-55 period was 1500 while in the last five years a more bi-modal pattern was evident with a single-hour peak of 12 events at 0900. The increased activity in the mid-morning hours of the 1956-60 period gives further credence

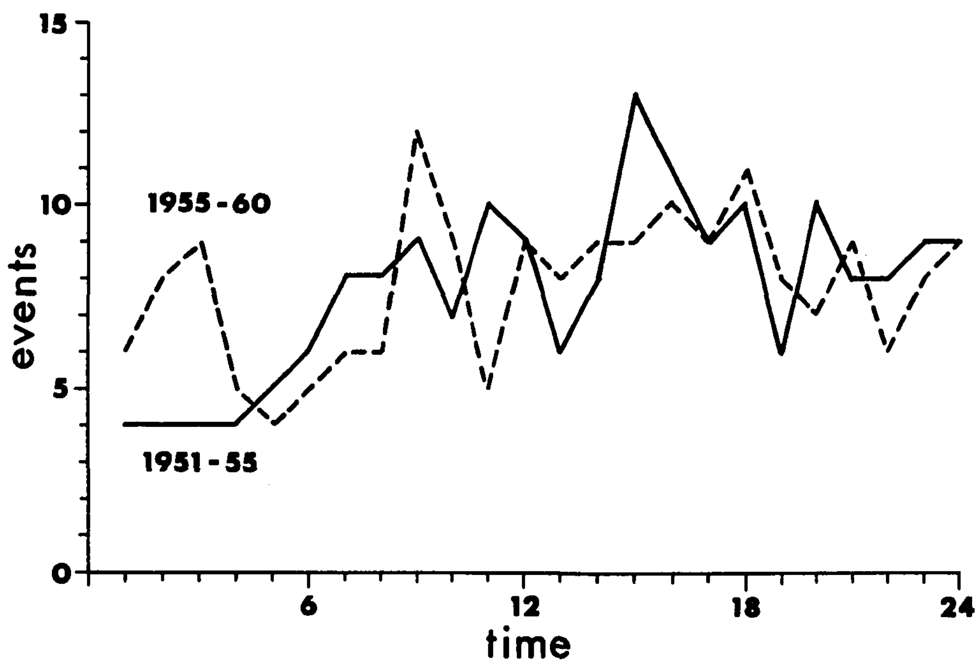

Figure 6-5 Frequency of January diurnal precipitation events for both the 1951-55 and 1956-60 periods for Lake Charles, LA.

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to the idea that when the polar front penetrates the Gulf frequently and the Texas-West Gulf cyclones are common, that these storms develop in the morning and the band of precipitation spreads northeastward into the Lake Charles area.

Analysis of the 1960's Data

Throughout the 1960's and 1970's, a distinct morning maximum of precipitation events was noted at Lake Charles. This mid-morning peak was shown to begin its' emergence in the latter half of the 1950's. Table 6-5 indicates some summary statistics describing the characteristics of events over the 24-hour period in the 1960's.

The shift to a morning peak was accompanied by a shift in peak intensities as well into the mid-morning hours. The hours between 0900 and 1100 had intensities of .10" or more and the two events of over 1.00" occurred during this time of the day.

Over the course of the 1960's, 500 hourly rainfall events were observed, a marked increase over the 1950's total. Of the three decades, the 1960's had the coolest mean temperature (49.6 degrees) and of the three decades, the 1960's had the greatest percentage of FOR events within any 10-year period, as shown in Table 6-6. Since the decade was cooler, that implies that the polar front was south of Lake Charles more often during this decade and frontal overrunning conditions were more prevalent from 1961-70 than during the other two decades.

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Table 6-5

Statistics associated with the diurnal distribution of hourly precipitation events: 1961-70

TIME	N	INT	ST.DEV.	MIN	MAX
0100	21	.08	.126	.01	.50
0200	14	.06	.067	.01	.23
0300	14	.03	.030	.01	.09
0400	17	.09	.219	.01	.93
0500	22	.04	.062	.01	.30
0600	21	.06	.096	.01	.42
0700	28	.06	.134	.01	.71
0800	29	.06	.100	.01	.46
0900	28	.10	.196	.01	1.03
1000	27	.10	.109	.01	.50
1100	27	.11	.253	.01	1.33
1200	25	.07	.073	.01	.25
1300	20	.06	.051	.01	.18
1400	21	.08	.120	.01	.51
1500	23	.08	.104	.01	.45
1600	22	.08	.099	.01	.39
1700	21	.07	.089	.01	.33
1800	21	.06	.082	.01	.35
1900	15	.05	.065	.01	.26
2000	18	.06	.058	.01	.25
2100	18	.05	.034	.01	.15
2200	18	.11	.148	.01	.59
2300	18	.04	.030	.01	.11
2400	18	.10	.163	.01	.65

The sharp dropoff in the frequency of CR and GR events in the 1960's is also tied in to the cooler weather patterns of that decade, since these types must have been less frequent in the 1960's due to the high frequency of polar air mass intrusion.

While the number of FOR events rose sharply in the 1960's (from 239 in the 1950's to 395 in the 1960's), the number of FGR events rose only from 94 to 99. The FOR increase, therefore, accounted for almost all of the increase in the frequency of hourly precipitation events from the 1950's to the 1960's. Table 6-7 displays some

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summary statistics associated with these four weather types in the 1960's.

Table 6-6
Percentage of events occurring in each decade, by type

TYPE	% OF 1950'S	% OF 1960'S	% OF 1970'S
CR	2.1	0.5	0.8
FGR	25.1	19.6	27.5
FOR	63.9	78.1	69.4
GR	8.8	1.8	2.3

Table 6-7

Statistics associated with the weather types: 1961-70

TYPE	N	INTENSITY	ST. DEV.	MIN	MAX
CR	3	.05	.055	.01	.11
FGR	99	.12	.210	.01	1.33
FOR	395	.06	.086	.01	.71
GR	9	.08	.059	.02	.20

The intensities for the two dominant weather types were near the 30-year mean and the 30-year maximum of 1.33" fell during a FGR event in the 1960's. As usual, the greatest variance in the values was found in FGR, which is expected due to the showery nature of these events which range from the negligible to the excessive.

The timing of events by weather types in the 1960's is shown in Table 6-8 and Figure 6-6. Once again, the GR events were clustered in the afternoon hours but the FOR events and the FGR events are most common in the morning hours. The frequency of FGR events peaks from 0500 through 0900 while FOR events peak between 0700 and 1100. The lag of peak FOR hours after the FGR peak indicates a

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"mean frontal passage" or "mean wave passage" around 0900. The bulk of the events between 1100 and 2000 are FOR events. While tabulating the data for the 1960's, it was apparent that during the mid-morning hours, waves would pass near or over the Lake Charles area as winds would often veer from northeast to southeast then back to northerly again during prolonged rainfall episodes. After the passage of the wave, the Lake Charles area would then be under FOR conditions until the wave passed far enough to the east that clearing would take place.

Table 6-8

Diurnal frequencies of hourly precipitation events by synoptic weather type: 1961-70

TIME	N	CR	FGR	FOR	GR
0100	21	0	6	15	0
0200	14	0	4	10	0
0300	14	0	1	13	0
0400	17	1	3	13	0
0500	22	0	7	15	0
0600	21	0	7	14	0
0700	28	0	7	21	0
0800	29	0	8	21	0
0900	28	0	8	20	0
1000	27	0	5	22	0
1100	27	0	3	24	0
1200	25	1	4	19	1
1300	20	0	2	18	0
1400	21	0	2	17	2
1500	23	0	3	18	2
1600	22	1	4	16	1
1700	21	0	4	16	1
1800	21	0	4	16	1
1900	15	0	1	13	1
2000	18	0	1	17	0
2100	18	0	3	15	0
2200	18	0	4	14	0
2300	18	0	4	14	0
2400	18	0	4	14	0

Since FOR and FGR combined to account for the mid-

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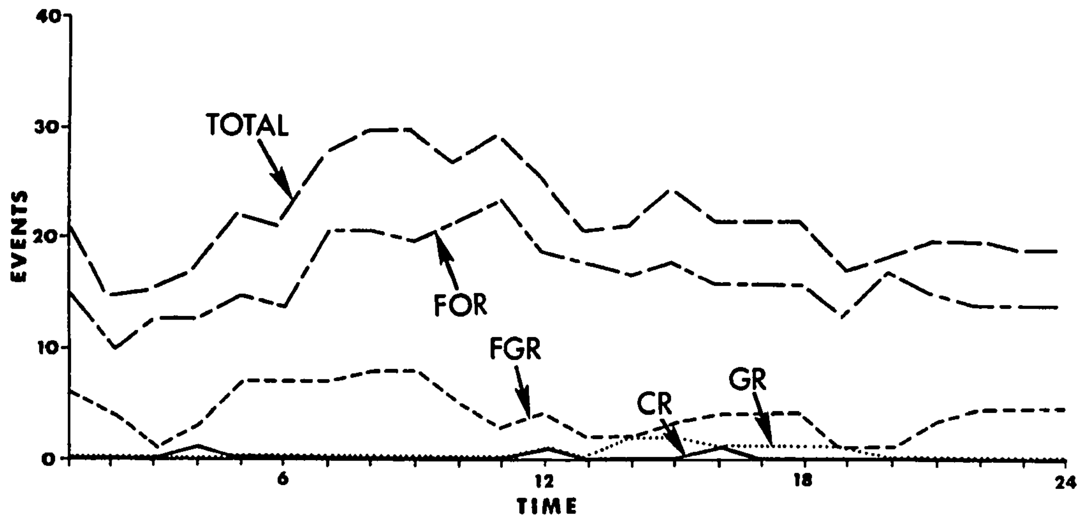

Figure 6-6 January diurnal frequency of hourly precipitation events (1961-70) by synoptic weather types at Lake Charles, LA.

morning peak, both of these types were significantly related to the overall distribution of diurnal events. FOR and the overall distribution were correlated at .90 while FGR and the overall distribution were correlated at .64. Coastal Return and Gulf Return were insignificantly related with the total distribution. What appears to be a secondary peak in the mid-afternoon hours is primarily a result of the cluster of GR events during that time.

The diurnal patterns for both the 1961-65 and the 1966-70 periods are practically identical. The main difference between the two periods is in the total number of events. The 1966-70 period had an increase in events of 50 over the first 5 years of the decade. Table 6-9 has the comparative statistics for these 5-year periods.

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Table 6-9

Statistics associated with the weather types: 1961-65 and 1966-70

TYPE	61-65 N	66-70 N	61-65 INT	66-70 INT	61-65 MAX	66-70 MAX
CR	3	0	.05	-	.11	-
FGR	68	31	.14	.08	1.33	.35
FOR	153	242	.07	.05	.71	.46
GR	4	5	.06	.09	.13	.20

As can be readily observed, the bulk of the increase in events was found to be associated with FOR weather in the latter 1960's. Rainfall intensities dropped in the two major types and the single heaviest event from 1966 through 1970 was only the .46" which fell in FOR weather. The mean temperature of the latter five years was slightly warmer than in the 1961-65 period, but the single greatest month for both total number of hourly events and total number of FOR events was January of 1966. In that month, 130 hours of rain fell, 121 of which were FOR events. The next highest total of hourly events was in 1978 which had a total of 108. The next highest total of FOR events occurred in 1973 with 78 hours of rainfall in FOR conditions, 42 fewer than in 1966. Table 6-10 summarizes the number of days and hours of rainfall for each January from 1951-80 and displays the average number of hours of rain per rainy day. As can be clearly seen, the number of hours per rainy day was highest in 1966 with 11.8 hours of rain per rainy day. The second highest hours per rainy day was in 1968 with an average of 8.1. The table shows

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that in the period from 1961-65 there were more rainy days but fewer hours of rain per day than in the 1966-70 period. The high values of hours of rain per rainy day in 1966 and 1968 accounted for the increase in events over the two 5-year periods.

The Januaries of 1966 and 1973, the Januaries with the greatest number of FOR events, were both months during El Nino events of varying intensity (Douglas and Englehart, p. 2378). Johnson, et. al. (1984) and others have indicated that stong El Nino years correspond with increased storminess in the Gulf of Mexico which in turn would lead to more FOR conditions as storms develop south of Lake Charles.

The abnormally wet Januaries of 1966 and 1968, therefore, gave the latter half of the 1960's a greater number of events despite the fact that the temperatures were slightly warmer in those latter five years.

Analysis of the 1970's Data

Of the three decades in this analysis, the 1970's were the wettest both in terms of total rainfall as well as total hours of rain. The mid morning peak was preserved throughout the decade and the mean temperature for the decade was slightly higher than that of the 1960's, rising from 49.6 degrees in the 1960's to 50.9 degrees in the 1970's.

Over the course of these ten years, 615 hours of rain occurred, 69% of which were FOR events. The relative

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Table 6-10

Number of days and hours of rainfall per January and average number of rainy hours per rainy day, 1951-80

YEAR	#DAYS	#HOURS	H/D
1951	13	77	5.9
1952	5	25	5.0
1953	5	14	2.8
1954	7	24	3.4
1955	8	44	5.5
1956	6	27	4.5
1957	11	27	2.5
1958	9	52	5.8
1959	9	45	5.0
1960	9	38	4.2
1961	11	79	7.2
1962	8	43	5.4
1963	8	36	4.5
1964	12	59	4.9
1965	3	13	4.3
1966	11	130	11.8
1967	7	27	3.9
1968	7	57	8.1
1969	6	34	5.7
1970	5	31	6.2
1971	5	21	4.2
1972	10	58	5.8
1973	15	94	6.3
1974	15	80	5.3
1975	9	36	4.0
1976	7	18	2.6
1977	11	59	5.4
1978	15	108	7.2
1979	10	66	6.6
1980	11	74	6.7

increase in FGR events to 27% can be accounted for by the warmer mean temperatures which resulted from milder weather patterns in some months, especially in the early 1970's. Table 6-11 shows the mean statistical characteristics of the hourly precipitation associated with the weather types.

The intensity of rainfall for GR events was at a decadal high of .17", largely due to a single event of .97" under GR conditions. FGR intensity remained at .12"

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Table 6-11

Statistics associated with hourly precipitation by weather type, 1971-80

TYPE	N	INT.	ST.DEV.	MIN	MAX
CR	5	.11	.126	.01	.32
FGR	169	.12	.186	.01	1.12
FOR	427	.07	.126	.01	1.27
GR	14	.17	.259	.01	.97

from the previous decade and FOR intensity rose slightly from .06" to .07" per hour. Even CR had it's decadal high intensity of .11" in the 1970's. Overall, however, even though intensities were somewhat higher in the 1970's than in the 1960's, they were still below the overall intensities of the 1950's. Intensities overall fell from .097" per hour in the 1950's to .072" per hour in the 1960's and then rose to .086" in the 1970's, a similar pattern to that of mean temperatures.

Throughout the 1970's, FOR weather had the best relationship with the overall diurnal pattern with a correlation of .88. The only other weather type to maintain a significant relationship with the overall diurnal pattern was GR which had a correlation coefficient of .55. Table 6-12 displays the diurnal variation in total events as well as those events attributed to the four weather types.

In the hours before noon, the relationship between FGR and FOR hours remains similar to those patterns found in the 1950's and 1960's. That is to say that prior to the peak in FOR hours, there is a peak in FGR hours, and

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Table 6-12

Frequency of rainfall events by weather type, 1971-80

TIME	N	CR	FGR	FOR	GR
0100	22	0	6	16	0
0200	18	0	3	15	0
0300	22	0	7	14	1
0400	24	0	8	15	1
0500	22	0	7	14	1
0600	28	0	7	20	1
0700	28	0	5	22	1
0800	33	0	7	25	1
0900	36	0	7	28	1
1000	37	0	7	29	1
1100	27	0	1	25	1
1200	29	0	7	21	1
1300	30	0	10	19	1
1400	26	0	7	19	0
1500	22	0	6	16	0
1600	20	0	5	15	0
1700	25	0	10	15	0
1800	29	1	10	17	1
1900	24	1	7	15	1
2000	21	0	8	12	1
2100	24	0	10	14	0
2200	24	1	10	13	0
2300	21	1	9	11	0
2400	23	1	5	17	0

immediately after the FOR peak, FGR drops off. However, the dropoff in FGR frequencies is short lived and from 1300 through 2300, FGR hours maintain a relatively high frequency with five hours reaching ten events. Prior to the 1970's, no single hour reached frequencies as high as ten over either 10-year period. The relative increase in FGR events in the afternoon resulted in a secondary overall peak centered around 1800. Coastal Return weather contributed its' five events in the latter part of the day, while GR events, which ideally should have been in the afternoon, were more likely in the morning. The distribution of FOR events in the 1970's is compatable with

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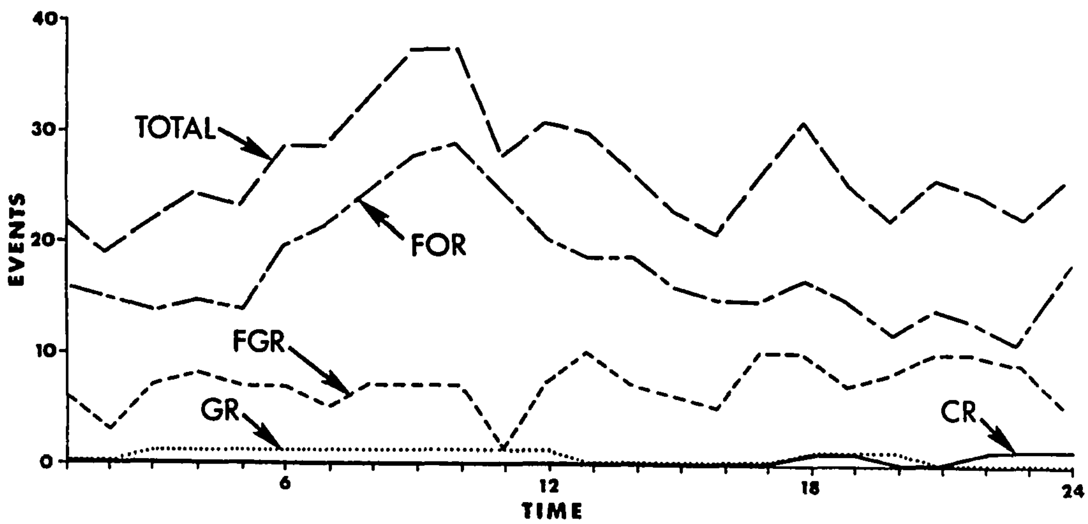

Figure 6-7 January diurnal frequency of hourly precipitation events (1971-80) by synoptic weather types at Lake Charles, LA.

that of the 1960's, however the increase in FGR events in the afternoon differs markedly from the pattern established in the 1960's.

Prior to the initiation of this research, it was assumed that FGR events might well peak in the afternoon hours. The afternoon peak in FGR events was assumed because under FGR conditions, unless there was a defined diurnal timing of frontal passages, FGR rainfall events would be most enhanced in the afternoon due to local convection derived from daytime heating. Data from the 1950's and 1960's, however, indicated that there was a diurnal timing to wave or frontal passages which skewed the frequency of FGR events to either the afternoon in the 1950's or the morning in the 1960's. The increase in FGR

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events in the late afternoon and evening of the 1970's is difficult to explain unless it is related to the increased local convection.

The mid-morning peak continued throughout the 1970's at Lake Charles, despite a shift in the timing of FGR events. Since FGR events make up so small a percentage of the total number of events, the overall distribution of diurnal precipitation in the 1970's was still dependent upon the timing of FOR rainfall which peaked at 1000.

<u>The Diurnal Pattern of the Onset of Extended FOR Events</u>

The 30-year diurnal precipitation pattern at Lake Charles was largely dependent upon the timing of FOR rainfall events. Even in the 1950's, when the overall peak was in the afternoon, FOR weather played the greatest role in determining that peak. The findings of this chapter are in overall agreement with the conclusions reached in the previous chapters. The passage of waves to the south and east of Lake Charles, the track which Elliott labelled Ga would leave Lake Charles in FOR conditions, conditions which peak around 0900 in the 1960's and 1970's. In the 1950's, with storm tracks displaced to the north, FOR conditions peaked later in the day, most likely related to the passage of fronts trailing from storms passing well to the north of the Lake Charles area.

If the peak in the frequency of hourly rainfall events at Lake Charles is related to the timing of cyclogenesis in the Gulf of Mexico and the subsequent northeastward

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migration of precipitation, then the majority of extended FOR events should begin in the early to mid-morning. In order to investigate this possibility, a set of conditions was devised to identify "extended" FOR events. The rules were as follows:

1) There must be at least 10 hours of FOR events within any 24 hour period.

2) The event may continue for more than 24 hours as long as there are no gaps longer than 8 hours with no precipitation.

3) There must be at least 6 hours with no precipitation prior to the onset of the event.

4) If the event lasted for more than 2 days, there may be no more than 24 hours with no precipitation interspersed within the event.

It is understood that these are quite subjective criteria but the purpose of creating these restrictions was to allow for some breaks in the data but not include events which were insignificant. After identifying the dates of these extended FOR events, The daily weather maps were reviewed in order to make sure that there was indeed a low pressure center or cyclogenesis in the Gulf.

As would be anticipated, most of the extended FOR events took place in the 1960's and 1970's. There were only 5 extended FOR events in the 1950's. In the 1960's, 13 events met these qualifications and 12 such events took place in the 1970's. Table 6-13 displays the number of times that an extended events began at any given hour of the day as well as the total number of events which were attributed to extended events over the 24-hour period.

Clearly, the time of day which had the greatest

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Table 6-13

The timing of the onset of "extended FOR events" and the diurnal variability of rainfall associated with these events

TIME	# OF FIRST HOURS	TOTAL HOURS
0100	2	20
0200		17
0300	2	19
0400	1	14
0500	2	16
0600	2	17
0700	5	27
0800	3	28
0900	1	30
1000	2	29
1100	2	28
1200		29
1300	1	29
1400		27
1500		26
1600	1	20
1700	2	22
1800		25
1900		22
2000	1	24
2100		22
2200	1	22
2300		21
2400	2	21

likelihood for the onset of a FOR extended event was after dawn and into the mid-morning hours. Between the hours of 0500 and 0800, 12 extended events were initiated, 40% of all such events over the 30-year period. Eighty per cent of all extended events began between midnight and 11 a.m. Since the criteria required to meet these conditions were quite strenuous, many shorter FOR events which were associated with Texas-West Gulf cyclones were ommitted from this sample; but the criteria were stringent so that FOR events associated with frontal passages would not be

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included. The timing of the onset of extended FOR precipitation at Lake Charles associated with these Texas-West Gulf cyclones agrees with the hypotheses stated in the qualitative model which explains the diurnal variation of cyclogenesis in the western Gulf of Mexico.

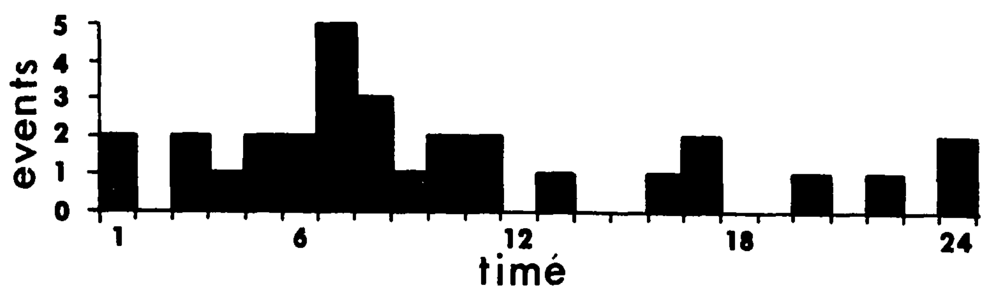

Figure 6-8 The number of "first hours" of measureable precipitation at the onset of extended FOR events (by time of day) during January, 1951-80 at Lake Charles, LA.

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CHAPTER VII

CONCLUSION

This research shows that the diurnal patterns of hourly precipitation events in Louisiana and southeastern Texas in January have varied over space and time. Distinct spatial patterns were discussed in both Chapter 3 and Chapter 4 where it was found that southern Texas had morning maximums throughout the study period while a southwest to northeast band of morning precipitation shifted south and east from eastern Texas in the 1950's into central Louisiana in the 1960's and 1970's.

The morning precipitation in southern Texas is the result of the diurnal variation in cyclogenesis, especially off the Texas-Gulf coast. The processes involved in the nocturnal development of these systems were defined in Chapter Four. The southwest to northeast band of mid-morning precipitation peaks is the result of the northeastward migration of weak disturbances which move to the northeast with the southwesterly flow aloft, well in advance of the Texas-West Gulf cyclone.

The band of mid-morning precipitation and its' associated transition zone with afternoon peaks shifted to the south and east in the 1960's and 1970's due to the more southerly displacement of the polar front. There is much evidence to support the more southerly postion of the polar

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front, including colder temperatures across the study region, a much greater frequency of frontal overrunning (FOR) rainfall events at Lake Charles in the 1960's and 1970's, and stronger winds and lower pressures aloft at Brownsville since 1958. This and other information related to the position of the polar front and increased cyclogenesis is included in both Chapters Five and Six. At Lake Charles, all extended frontal overrunning (FOR) events, as defined in Chapter Six, were associated with cyclogenesis in the Gulf of Mexico. Forty per cent of all of these events were initiated between 0500 and 0800 and 80% were intitiated between 2400 and 1100. This is further evidence to support the idea that cyclogenesis in the western Gulf is highly nocturnal. Furthermore, of the 30 extended FOR events, only 5 were in the 1950's, a decade in which Lake Charles had an afternoon rainfall maximum.

The transition zone between morning and afternoon precipitation maximums shift to the Florida panhandle in February. This shift takes place because the mean position of the arctic high shifts eastward as does the axis of the arctic air outbreaks across the eastern United States. Storm tracks in the south and eastern parts of the United States are also displaced eastward in late winter and spring.

This research is of interest to weather forecasters, not just in Texas and Louisiana, but also throughout much of the southern and eastern United States. As Saucier stated, the weather in the eastern United States during the

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winter months is affected by the "frequency and behavior of extratropical cyclones originating near the northwestern coast of the Gulf of Mexico." (p. 219) Many of the snowstorms in the south are caused by these storms and, according to Johnson and Mortimer (1985), 80% of all heavy snowfall events (22) in Louisiana from 1948 through 1985 occurred when there was a low pressure system in the northwestern Gulf. To the northeast, many more snow and ice storm events may be traced to Texas-West Gulf cyclones. Since these storms are such a nuisance in the South, the understanding of the diurnal characteristics of cyclogenesis is of significant interest.

On a more local level, the existence of the southwest to northeast band of morning precipitation has never before been documented. Forecasters may use this information to allow for increased rainfall probabilities along this band when cyclogenesis is occurring in the western Gulf of Mexico.

Since climatologists have not attempted to look at fluctuations in diurnal rainfall patterns over time, it is quite likely that there are other areas which have undergone similar changes in diurnal patterns, perhaps even in other seasons. Future research could encompass the entire Gulf Coast to incorporate the findings of this research and that of Schwartz and Bosart. This would also entail a study of diurnal rainfall patterns throughout the winter-spring season so that the shifting of the storm tracks (and the transition zone) could be analyzed.

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On a larger scale, the findings related to diurnal precipitation patterns and associated atmospheric circulation variability raise questions about climate fluctuations in the past thirty years. An analysis of weather conditions in the 1900-1920 period, when apparently similar temperature and rainfall patterns existed, could shed some light on this. Hopefully, the findings of this research will stimulate more detailed analyses of diurnal precipitation patterns over space and time and their relationships with atmospheric processes.

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APPENDIX A

CLIMATE STATIONS INCLUDED IN THE STUDY AREA
AND THE DECADES IN WHICH DATA WAS COMPILED

STATION	1950'S	1960'S	1970'S	YEARS MISSING
	TEXAS			
Austin, TX (AUS)	XX	XX		
Bay City, TX (BC)	XX			
Benavides, TX (BEN)	XX	XX		1969
Bon Weir, TX (BW)		XX		
Brownsville, TX (BVL)	XX	XX	XX	
Calhoun, TX (CAL)	XX			
Cheapside, TX (CHP)	XX	XX		
Conroe, TX (CRO)	XX	XX		1951
Corpus Christi, TX (CC)	XX	XX	XX	
Crabb, TX (CRB)	XX			
Eagle Pass, TX (EP)	XX			1960
Galveston, TX (GAL)	XX	XX	XX	
Hindes, TX (HIN)	XX	XX		1951
Houston, TX (HOU)	XX	XX		
Jewett, TX (JEW)	XX	XX		1961
Kountze, TX (KTZ)	XX	XX		
Laredo, TX (LAR)	XX	XX		
Latex, TX (LTX)	XX			
Lexington, TX (LEX)	XX	XX		1968
Lovelady, TX (LOV)	XX	XX		
Nacogdoches, TX (NAC)	XX	XX		
Port Arthur, TX (PA)	XX	XX		
Randolph Field, TX (RF)*	XX	XX		
Rockland, TX (RKL)	XX	XX		
Sarita, TX (SAR)	XX	XX		1951
Shepherd, TX (SHP)	XX			
Somerville, TX (SOM)	XX	XX		
Tatum, TX (TAT)		XX		
Thompsons, TX (TPS)		XX		
Victoria, TX (VIC)	XX	XX		
Weslaco, TX (WES)		XX		
Wheelock, TX (WHL)		XX		
William Harris Res. (WHR)	XX			
Zapata, TX (ZAP)	XX			1951

*San Antonio

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STATION	1950'S	1960'S	1970'S	YEARS MISSING
		LOUISIANA		
Alexandria, LA (ALEX)		XX		1968
Batchelor, LA (BAT)	XX			
Baton Rouge, LA (BTR)	XX	XX	XX	
Bernice, LA (BER)	XX			
Catfish Point, LA (RF-CP)*		XX		
Clinton, LA (CL)	XX	XX		1953, 1954
Darnell, LA (DAR)	XX			
French Settlement, LA (FS)	XX	XX		1969
Grand Isle, LA (GI)	XX			
Harrisonburg Dam, LA (HBD)	XX			
Keithville, LA (KV)	XX	XX		
Lafayette, LA (LAF)	XX			
Lake Arthur, LA (LA)	XX			
Lake Charles, LA (LC)	XX	XX	XX	
Leesville, LA (LEE)	XX	XX		
Lettsworth, LA (LET)	XX	XX		
Logansport, LA (LPT)		XX		
Monroe, LA (MRO)	XX	XX		
Montgomery, LA (MON)	XX			
Morgan City, LA (MC)	XX	XX		
New Orleans, LA (NO)	XX	XX	XX	
Olla, LA (OLA)		XX		
Opelousas, LA (OP)	XX	XX		1969, 1970
Pollock, LA (POL)		XX		
Robson, LA (ROB)	XX			
Ruston, LA (RUS)	XX	XX		
Shreveport, LA (SHV)		XX	XX	
Vermillion Lock, LA (VL)	XX			
Vidalia, LA (VID)		XX		
Winnsboro, LA (WBR)		XX		

*Rockefeller Wildlife Refuge, 1966-70

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APPENDIX B

SIGNIFICANT DIURNAL PEAKS OF HOURLY PRECIPITATION EVENTS

1951-60

STATION	STANDARD DEV.	TIME >1 S.D.	TIME >2 S.D.
Austin, TX	3.8	0700 - 1100	none
Bay City, TX	2.6	1200 - 1500	1300 - 1400
Benavides, TX	2.2	0100 - 0600	none
Brownsville, TX	2.8	0100 - 0600	0300 - 0500
Calhoun, TX	1.7	02-03,08-12,14-17	none
Cheapside, TX	1.8	01, 08-11, 23	0800 - 0900
Conroe, TX	2.3	0100 - 1300	1100
Corpus Christi	2.4	0100 - 0800	none
Crabb, TX	2.9	1100 - 1500	1300
Eagle Pass, TX	2.5	0200 - 0400	0200 - 0300
Galveston, TX	2.7	1400 - 1700	1500
Hindes, TX	2.3	01-03, 07-10	0200
Houston, TX	3.8	1400 - 1700	1500 - 1600
Jewett, TX	2.1	01-02,08,22-24	2300 - 2400
Kountze, TX	4.0	1400 - 1600	none
Laredo, TX	3.3	02, 0600 - 0900	none
Latex, TX	1.2	01-02, 06, 13	0100
Lexington, TX	1.5	04-06, 22-24	0400
Lovelady, TX	1.4	04-05, 12-14	1200 - 1300
Nacogdoches, TX	2.8	0300, 1400	none
Port Arthur, TX	2.8	1400 - 1800	1600
Randolph Field	2.0	03, 0700 - 0900	none
Rockland, TX	2.1	0700 - 1000, 15	none
Sarita, TX	1.8	0100 - 0500	0200 - 0400
Shepherd, TX	2.8	0100 - 0400	0300
Somerville, TX	2.2	02-04, 10-12	none
Victoria, TX	2.5	0900 - 1100	0900 - 1000
W.H. Harris Res.	2.4	03, 12, 14-16	1500
Zapata, TX	1.8	0100 - 0400, 08, 24	0200 - 0300
Batchelor, LA	3.2	1500 - 2000	none
Baton Rouge, LA	2.0	1700 - 2000	1900 - 2000
Bernice, LA	2.9	0900 - 1200	1000
Clinton, LA	2.4	08, 1700 - 2000	none
Darnell, LA	3.8	01-03, 16-17	0200
Fr. Settlement	2.8	1600 - 1900	1700
Grand Isle, LA	2.8	09, 1400 - 1600	none
Harrisonburg D.	2.8	01-03, 16-17, 24	none
Keithville, LA	2.5	1000 - 1500	1200 - 1300

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STATION	STANDARD DEV.	TIME >1 S.D.	TIME >2 S.D.
Lafayette, LA	1.6	1600 - 1900	1700 - 1900
Lake Arthur, LA	3.8	10, 1500 - 1900	1700
Lake Charles, LA	3.2	1500 - 1700	none
Leesville, LA	3.5	1400 - 1800	none
Lettsworth, LA	2.6	1500 - 2000	none
Monroe, LA	3.3	1000 - 1500	none
Montgomery, LA	2.2	10-11, 1400 - 1600	none
Morgan City, LA	1.6	09-10, 1800 - 2000	0900, 1900
New Orleans, LA	1.7	1300 - 1500, 17, 22	1500
Opelousas, LA	2.3	1400 - 1800	1500 - 1600
Robson, LA	3.7	0800 - 1100	0900 - 1000
Ruston, LA	2.9	09, 1300 - 1500	none
Vermillion Lock	1.1	1600 - 1800	1700
		1961-70	
Austin, TX	3.9	05, 0700 - 1100	none
Benavides, TX	1.6	01, 03-05, 16-17	none
Bon Weir, TX	3.5	0800 - 1100	none
Brownsville, TX	4.1	0600 - 0900	none
Cheapside, TX	2.4	03, 08-09, 15	0900
Conroe, TX	3.1	01, 0900 - 1200, 14	none
Corpus Christi	4.0	0200 - 0900	none
Galveston, TX	3.9	1100 - 1300	none
Hindes, TX	2.3	01-02, 0800 - 1100	0900 - 1000
Houston, TX	3.6	09-10, 1200 - 1700	none
Jewett, TX	3.9	1300 - 1700	none
Kountze, TX	4.6	1200 - 1500	none
Laredo, TX	2.9	0200 - 0500	none
Lexington, TX	1.9	0200 - 0300	none
Lovelady, TX	4.0	0800 - 1200	none
Nacogdoches, TX	2.7	0800 - 1200	none
Port Arthur, TX	3.5	0700 - 1100	0900
Rockland, TX	3.8	0300	none
San Antonio, TX	4.3	0400 - 0700	0600
Sarita, TX	2.7	01-03, 23-24	none
Somerville, TX	5.4	0800 - 1200	1000
Tatum, TX	1.0	01-03,11,16,22-24	23,24,01
Thompsons, TX	3.0	0500, 0900 - 1200	1000
Victoria, TX	3.9	02-03, 0800 - 1100	none
Weslaco, TX	3.2	0700 - 0900	0800
Alexandria, LA	2.5	0700, 1600 - 1800	1800
Baton Rouge,LA	3.9	1700 - 2200	none
Catfish-Rock.	1.9	0700, 1100	none
Clinton, LA	3.0	0900, 1600 - 2000	none
Fr. Settlement	4.9	1800 - 2200	none
Harrisonburg D.	5.0	1400 - 1800	none
Keithville, LA	3.2	0900 - 1400	none
Lake Charles, LA	3.8	0700 - 1100	none
Leesville, LA	3.0	07-08, 1400 - 1700	none
Lettsworth, LA	3.6	08-09, 11-12	1100 - 1200
Logansport, LA	2.5	12-14, 16-19	1700 - 1800
Monroe, LA	1.7	11, 13, 1500 - 2000	none

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STATION	STANDARD DEV.	TIME >1 S.D.	TIME>2 S.D.
Morgan City, LA	2.0	08-09, 1700 - 2000	1800 - 1900
New Orleans, LA	2.6	16-17, 22, 24	none
Olla, LA	3.1	0800 - 1200	1000 - 1100
Opelousas, LA	3.3	13-15, 18-19	none
Pollock. LA	2.9	0800 - 1100	0900 - 1000
Ruston, LA	2.6	1100 - 1800	none
Shreveport, LA	2.7	0800 - 1000, 17-18	none
Vidalia, LA	3.6	09, 11-12, 16	none
Winnsboro, LA	2.9	08-09, 1600 - 1900	none

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VITA

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Birthplace and date: Memphis, TN, July 8, 1955

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Current Employment: Assistant Professor, Geography Department, Bowling Green State University.

Education: B.A. Memphis State University, Memphis, TN.
1978 Major: Geography
History

M.S. Memphis State University, Memphis, TN.
1980 Major: Geography (physical)

Graduate study: M.S.U., History. 1980-81
L.S.U., Geography (history minor) 1982-85
(passed dissertation defense February 6, 1986)

Teaching Experience:

Teaching Assistant (physical geography labs), Memphis State University (1978-80).

Teaching Assistant (American history), Memphis State University (1980-81).

Teaching Assistant (Cultural Geography), Louisiana State University. (1984-85).

Assistant Professor, Department of Geography, Bowling Green State University (1985-).

Research Experience:

Research Assistant, Louisiana Office of State Climatology (1982-1984).

Publications:

Co-editor of _A Climatic Perspective of the_

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Louisiana Floods, 1982-83. Geoscience Publications, Department of Geography and Anthropology, Louisiana State University.

Co-author of A Climatic Perspective of the Louisiana Floods, 1982-83.

Co-author of An Application of Climatic Indices Relevant to Heat Stress and Summer Comfort: Baton Rouge, Louisiana in July. Climate Paper 85-2, June, 1985. Office of State Climatology, Louisiana State University, Department of Geography and Anthropology, Baton Rouge, LA

Papers presented at Professional meetings:

April 24, 1985 and February 4, 1986: "Spatial and Temporal Trends in Excessive Hourly Rainfall Events in South Louisiana, 1951-1980." Association of American Geographers meeting, Detroit, Mich.

Nov. 22, 1985: (with Gregory J. McCabe) "Cloud modification and enhancement over an industrial site in Baton Rouge, Louisiana." Presented at the Annual Meetings of the Southeastern Division of the Association of American Geographers.

General Fields of Interest: climatology (precipitation, water balance, synoptic, historical), natural hazards (snow and floods), present and past impacts of weather in U.S. cities.

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DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Gregory E. Faiers

Major Field: Geography

Title of Dissertation: THE FORMATION AND GEOGRAPHIC RELOCATION OF JANUARY DIURNAL PRECIPITATION PATTERNS IN LOUISIANA AND SOUTHEASTERN TEXAS

Approved:

Robert A. Muller
Major Professor and Chairman

[illegible]
Dean of the Graduate School

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Paul F. Paskoff

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Richard L. Bergstrom

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Date of Examination:

February 6, 1986

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